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WIRELESS SOUND SYSTEMS

BY

C. W. HARGENS [1]

The advent of the transistor now makes wireless sound systems practical in certain applications where a conventional public address system is not desirable. The system described below, which has been used at The Franklin Institute, points out one successful application of the wireless technique. In the evolution of the wireless sound system, factors of psychological, economic and aesthetic as well as technical origin are considered.

Franklin Hall is a large memorial hall which is frequently used for dinner meetings. It has a reverberation time of several seconds, so that it is impossible to understand spoken sentences without some form of public address system or other acoustic aids. When powerful loud speakers were installed, the increased level of sound emphasized the reverberations and produced distorted sound of an extremely unpleasant character.

This type of acoustic problem might appropriately be solved through the use of a multitude of small speakers located about the room. On the other hand, the magnificent beauty of the hall with its great marble walls could not be marred by the presence of electronic appliances. Also, the task of wiring such a system would present extreme difficulty (Fig. 1). A wireless system was therefore indicated, and its development was undertaken by The Franklin Institute Laboratories.[2]

The wireless sound system employs no new electrical principles; in fact, versions of the idea have been used for several decades. The phonograph oscillator which was used in household record players to provide a wireless connection with a broadcast receiver in the same room has been a practical applicance. Here, the low-power oscillator as-

[1] Senior Staff Engineer, Electrical Engineering Division, The Franklin Institute Laboratories for Research and Development, Philadelphia, Pa.

[2] Preliminary trials were made in the spring of 1955. The Regency receivers used at the trial meetings were loaned to the Institute through the courtesy of the manufacturer.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

sociated with the record player radiated very little power so as not to interfere with neighborhood radios.

In the present application each dinner table is equipped with a miniature radio receiver employing transistors instead of vacuum tubes. The speaker of the occasion then broadcasts his remarks to the receivers with the aid of a transmitter located within the room and connected by wire to the microphone. A vest-pocket portable transmitter was considered but seemed to present more serious problems than were justified by the slight advantage that would be gained.

FIG. 1. View of Franklin Hall taken during one of the trial dinners in the spring of 1955.

The system described in this paper owes its development to the marvelous efficiency of miniature receivers using transistors. The current drain (from a single 22½-volt battery) for the four-transistor receivers used was less than 4 milliamperes. With this low value of current consumed in the transistor circuit, a long battery life can be expected in the type of service considered here.

This type of communication system comes under the purview of the Federal Communications Commission only in a mildly regulatory sense. The ruling of the FCC states that no license is required if the field strength at distances greater than $\frac{\lambda}{2\pi}$ (about one-sixth of a wavelength) is less than 15 microvolts per meter.

If this requirement is studied critically, one finds numerous aspects which support the adoption of the proposed system. At first it might seem that a very small signal strength is allowed, and in fact so small as to make a system which depends upon levels of this order unreliable. Moreover, man-made interference, static and even the noise generated in the input of small receivers are audible when one attempts to listen to such weak signals.

However, the situation with respect to field strength is actually far brighter than the comments above would indicate. Experiments showed that large, modern buildings present a considerable electromagnetic shielding effect. One is often aware of this shielding when a radio is set up for use at the office. If the receiver is not located near a window or other opening, it is difficult to receive even the strong local stations. In the absence of the building's structural steel, concrete reinforcing rods, metal lath, and other materials the signal strength from local stations would be perhaps 5000 to 10,000 microvolts per meter. Actually it is only a few hundred microvolts per meter as a result of the building's attenuation.

The shielding effect works to the advantage of the wireless sound system in two ways: first, it permits the use of a strong signal within the building while not exceeding the FCC ruling outside; and, secondly, it attenuates the signals from strong broadcasting stations which might otherwise interfere with operation of the system. This selective shielding which favors reception of the signals from the system transmitter is further enhanced by the automatic-volume-control action in the receivers. That is, the strength of the system signal tends to reduce the receivers' sensitivity, further insuring against interference from broadcasting stations.

The transmitter should be designed to take full advantage of the shielding of the particular building. That is, its output capabilities should be great enough to drive a large antenna so that the combination will be able to produce the maximum allowable signal strength outside of the building. The extent to which this desirable condition is realized is a matter for experiment and measurement. One must therefore use a field strength meter for this work in order to determine when the optimum power has been reached.

The selection of a transmitting frequency for Franklin Hall was based upon the $\frac{\lambda}{2\pi}$ restriction and upon the fact that transistor receivers were available only in the broadcast band. The 550 and 1600 KC limits of the broadcast frequency spectrum yield a $\frac{\lambda}{2\pi}$ of 273 and 94 ft., respectively. Thus, the lower radio frequencies used for commercial broadcast are preferred for this application over high frequency FM or other selections based upon possibly simpler electronic components.

Regardless of the selected frequency, the transmitting equipment required is relatively simple. The system described here was intended primarily for speech; hence, the audio frequency response specification was less strict than for music. These considerations resulted in the choice of a grid modulation arrangement in the transmitter design. Figure 2 shows the method used for modulating the RF power amplifier through the application of the audio signal to two grids.

The oscillator and RF amplifier were housed in a shielded compartment, separate from the audio section. The construction of the oscillator can be made sufficiently stable as to frequency drift so that crystal control is unnecessary. This leniency is partly a result of the

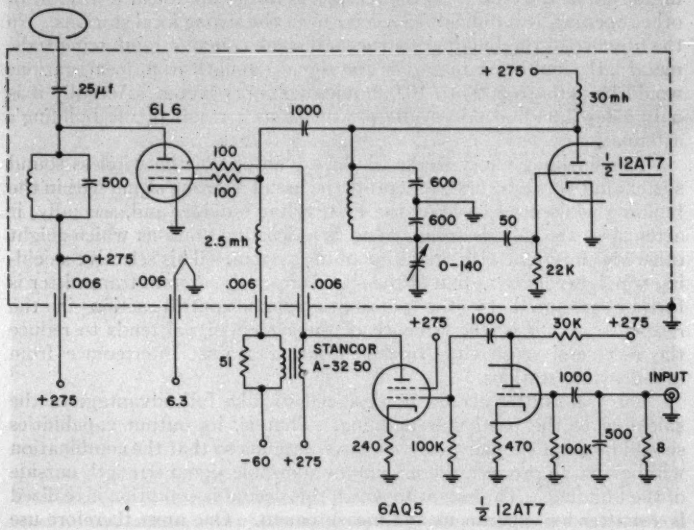


FIG. 2.

mediocre selectivity of most small receivers. However, long-time frequency stability is essential so that the transmitter can operate for hours at a time without drifting from the preset tuning of the receivers.

The transmitter was designed to utilize any public address amplifier as modulator. Thus, the transmitter took the form of an attachment to be used with an existing amplifier which was capable of driving an 8-ohm load. In this way multichannel inputs, mixing circuits, and other features of the previous sound installation were retained intact. Figure 3 shows the diminutive size of the transmitter.

Tests with various kinds of antennas have indicated that a very long

conductor is most effective in producing a uniform field in the room. Since the coupling between the transmitter and the ferrite core-type antennas in the receivers is principally through induction, the field produced by the long conductor is most satisfactory. Best results were obtained when the antenna formed a great loop encompassing the entire room and resting upon a fascia at the top of the walls. In this location (approximately 60 feet high) the conductor was nearly equidistant from all receivers, and uniform coverage was obtained.

FIG. 3.

A number of points should be mentioned in connection with the way in which the receivers are used. First, it is important to set the volume level of each receiver so that it will be as low as possible consistent with the listeners' needs and yet not induce reverberations in the room. It is extremely difficult to make this adjustment by ear when a number of receivers have been set in operation. Further facilities are helpful here. These include the provision of an audio note in the transmitter, either by the substitution of an oscillator at the input or by switching some parameter in the transmitter so as to cause a temporary oscillation.

Some of the miniature receivers are now designed with a small hearing aid jack in the output for personal listening. An expedient method

for setting the audio level was to connect a rectifier-type meter into this circuit and make adjustments with respect to the audio note from the transmitter. Three adjustments made were: tuning, orientation of the receiver for maximum pick-up in the ferrite rod antenna, and volume setting.

In order to preserve the settings just mentioned it was found necessary to place the receivers inside a tamper-proof housing while in use. At the dinner table it appears to be difficult for even the most elite group to control the pressure of curiosity and refrain from investigating the receiving instruments. Therefore, the receivers require some modification for this use.

The participation of an audience is required in the final adjustment of most large acoustical systems. Also, in making volume adjustments the use of a sound level meter is very helpful in assuring uniform sound intensity and in locating dead spots. By these means one is aided in deciding upon the appropriate receiver output setting and in placing the acoustical measurements upon a reproducible basis.

Mention should also be made of the impression the speaker receives with such a low acoustical level. The effect is noticeably different from conventional systems. With conventional public address equipment the speaker hears his own voice booming back with great strength. To some this is reassurance of the fact that they are "getting across" and being heard.

With the wireless system operating in a large hall one may feel a little as though he is talking to himself, for very little sound is returned to the speaker from the receivers. If this is a difficulty, it is quickly overcome as soon as one gains confidence that everything is really functioning properly and realizes that conditions are similar to those prevailing in a broadcasting studio.

Psychologically the audience may become slightly detached, because at times listeners tend to look toward the source of the sound, in some instances away from the speaker. The speaker's eye contact with this part of his audience may then be disturbed, and he may feel some competition from the receivers. However, as soon as the novelty of the arrangement disappears, people tend to look toward the speaker. This is of course dependent upon the receiver designer's ability to make the table instrument uninteresting to look at and the speaker's ability to make his speech interesting to hear.

As experience is gained with this system, undoubtedly improvements can be discovered which will make its operation more pleasing to all. The long-term efficiency and maintenance problems do not appear to present any particular difficulties. It is also to be expected that those who see and hear the equipment in operation will conceive of other interesting applications of wireless sound systems employing transistor receivers.

ON THE THEORY OF A TWO-STAGE A-C. ROTARY AMPLIFIER

BY

E. MISHKIN [1]

1. INTRODUCTION

We shall try in what follows to develop the basic characteristics and the principal performance data of a two-stage, phase sensitive a-c. rotary amplifier. Our aims will be:

(*a*) to explore the realizibility of such an amplifier,
(*b*) to get an intimate insight of the amplifier's nature,
(*c*) to prepare for the development of an equivalent circuit diagram and eventual block diagram, and
(*d*) to find the machine's performance under various load and input conditions.

This search was made before any machine-model, based on the principles outlined below, was ever built. It cannot therefore benefit from any observations made in the laboratory under various tests. It seems consequently that the safest procedure to adopt is to base the analysis on Maxwell's fundamental field equations, that is, derive the various relations from the solution of the electromagnetic field in the machine's air-gap.

2. PRINCIPLE OF OPERATION

Figure 1 presents a schematic connection diagram of a two-stage a-c. rotary amplifier with a d-c. input (*A* winding) and an a-c. three-phase output (*D* winding). The machine consists of a rotor and a stator both

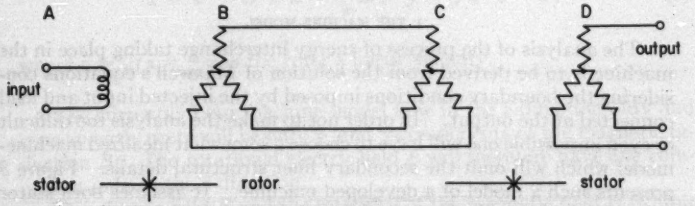


FIG. 1. Schematic connection diagram.

laminated and having slots carrying the *B* and *C*, and *A* and *D* windings, respectively. The two stages—windings *A* and *B*, and windings *C* and *D*—are to be magnetically noninteracting. A d-c. input voltage is ap-

[1] Microwave Research Institute, Brooklyn Polytechnic Institute, Brooklyn, N. Y.

plied to the A winding which is to be arranged similarly to the field windings of a synchronous machine. The moving rotor causes emf.'s to be induced in the three-phase B winding. The three-phase C winding is connected, as a load, across B—its phase sequence being opposed to that of B. The magnetic field associated with the currents in the C winding constitutes a forward (in the direction of the rotor's movement) moving wave inducing emf.'s in the output D winding.

Figure 2 shows one method of winding whereby the two stages A, B and C, D are magnetically noninteracting *viz.* that of halving the pole pitch. Only one conductor per pole is shown, the conductors being distributed over the smooth rotor and stator surfaces.

It is obvious that different methods of windings and winding arrangements can be developed along these principles.[2]

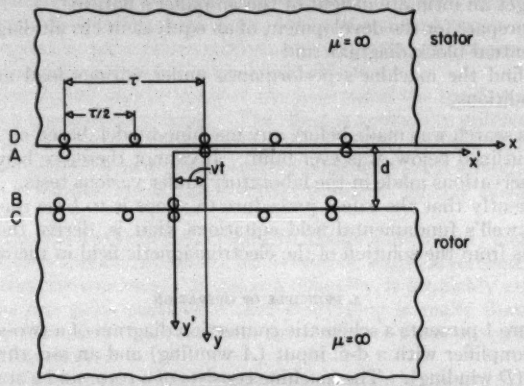


FIG. 2. Principle of winding (developed machine).

3. THE MACHINE-MODEL

The analysis of the process of energy interchange taking place in the machine is to be derived from the solution of Maxwell's equations considering the boundary conditions imposed by the injected input and load connected at the output. In order not to make the analysis too difficult or even impossible one will have to choose a somewhat idealized machine-model which will omit the secondary finer structural details. Figure 3 presents such a model of a developed machine. It assumes both stator and rotor to be made of perfectly permeable steel sheets ($\mu = \infty$) both having smooth surfaces. The conductors which are actually embedded, relatively deep, in the stator or rotor slots are to be distributed along the surfaces and their radial thickness assumed infinitesimal. The

[2] See E. MISHKIN, "On Some Poly-Field A.C. Amplifiers," to be published in the *Transactions* of the A.I.E.E.

machine is very long compared to the length d of the air gap. In other words, the ends effect is neglected and the whole problem is converted into a two-dimensional one. All this will cause a substantial quantitative difference in the magnitude of the leakage fluxes which can be made up by an increase in the effective length of the air gap.

The circumferential distribution of all the windings, their relative position and the number of turns are to be preserved.

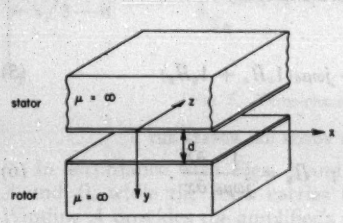


FIG. 3. Model of the a-c. rotary amplifier.

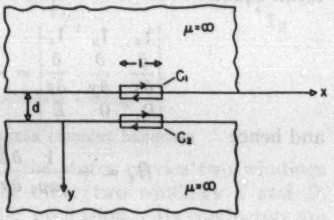


FIG. 4. Contours for establishing the boundary conditions.

4. THE DIFFERENTIAL EQUATION OF THE FIELD IN THE AIR GAP

We shall choose a right hand cartesian coordinate system $OXYZ$ (see Figs. 2 and 3) so that the x-axis will coincide with the stator's inner surface. The z-axis will run in parallel with the machine's shaft and the y-axis, perpendicular to both, shall point towards the rotor. In addition to this stationary system, we shall use another right hand cartesian coordinate system $O'X'Y'Z'$ parallel to the previous one and tied to the moving rotor. The relationship between the corresponding coordinates is

$$x = x' - vt = x' - \frac{\tau}{\pi}\omega t; \quad y = y'; \quad z = z', \tag{1}$$

where $v = 2f\tau = \frac{\tau}{\pi}\omega$ is the rotor's linear velocity.

The currents in our machine-model flow in the z-direction only and consequently there will be only x- and y-components of the magnetic induction B. The rotational electric field E will therefore have one component only in the z-direction.

The electric field E and the intensity of the magnetic field H exhibit both a sinusoidal time dependence

$$E = \bar{E}e^{j\omega t}; \quad H = \bar{H}e^{j\omega t}. \tag{2}$$

$\bar{E}$ and $\bar{H}$ are the time independent complex amplitudes (phasors) and ω is the circular frequency. Maxwell's second equation

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{3}$$

applied in the air-gap region yields

$$\nabla \times \bar{E} = -j\omega\mu_0\bar{H} \tag{4}$$

where $\mu_0 = 4\pi 10^{-7}$ is the permeability of the free space. The last vectorial equation can be rewritten more explicitly

$$\begin{vmatrix} 1_x & 1_y & 1_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & 0 & \bar{E} \end{vmatrix} = -j\omega\mu_0(1_x\bar{H}_x + 1_y\bar{H}_y) \tag{5}$$

and hence

$$\bar{H}_x = -\frac{1}{j\omega\mu_0}\frac{\partial\bar{E}}{\partial y}\,; \quad \bar{H}_y = \frac{1}{j\omega\mu_0}\frac{\partial\bar{E}}{\partial x}\,. \tag{6}$$

Maxwell's first equation, applied to the air gap,

$$\nabla \times \bar{H} = \begin{vmatrix} 1_x & 1_y & 1_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \bar{H}_x & \bar{H}_y & 0 \end{vmatrix} = 0, \tag{7}$$

leads to

$$\frac{\partial\bar{H}_y}{\partial x} - \frac{\partial\bar{H}_x}{\partial y} = 0. \tag{8}$$

From Eqs. 6 and 7 one obtains the two dimensional Laplace equation of $\bar{E}$ in the air gap

$$\frac{\partial^2\bar{E}}{\partial x^2} + \frac{\partial^2\bar{E}}{\partial y^2} = 0. \tag{9}$$

5. THE BOUNDARY CONDITIONS

The solution of the differential equation (9) is to fulfill certain boundary conditions imposed on the machine by the source at the input of the amplifier and by the load connected to its output. More directly these boundary conditions can be obtained from computing the line integrals of $\bar{H}$ along the two contours C_1 and C_2 shown in Fig. 4. These contours are of unity length in the x-direction and infinitesimal in the y-direction. As we assumed perfect permeable cores ($\mu = \infty$)—there is no magnetic field in them and hence

$$\bar{H}_{x(y=0)} = -\bar{A}_{st.}, \tag{10}$$

$$\bar{H}_{x(y=d)} = \bar{A}_r, \tag{11}$$

where A_{st} and A_r are the linear current densities of the stator and rotor respectively or the ampere-conductors surrounded by the above mentioned contours.

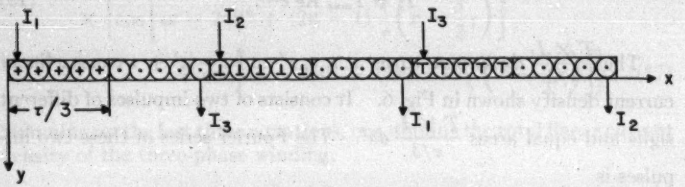


FIG. 5. Three-phase schematic winding.

6. THE STATOR AND ROTOR LINEAR CURRENT DENSITIES

In accordance with Figs. 1 and 2 the stator carries two windings A and D, while the rotor carries the other two windings C and D. Winding A provides the amplifier's d-c. excitation. Its conductors are to be sinusoidally distributed along the stator's surface all carrying the same input current I_A. The spatial distribution of the linear current density A_A of this winding constitutes a sinusoidal standing wave with regard to the stator.

$$A_A = A_{A\max} \cos \frac{\pi}{\tau} x = A_{A\max} \operatorname{Re} e^{-j(\pi/\tau)x}, \tag{12}$$

where τ is the pole pitch. "Re" (the real part of) will be omitted in the following notations.

Figure 5 presents a schematic three-phase wiring diagram, for example, the B winding. It consists of very thin evenly distributed conductors all, of each phase, connected in series. There are T turns per phase arranged over a phase spread of $\tau/3$ where τ is the pole pitch. We shall choose the coordinate system AOX so that its origin will coin-

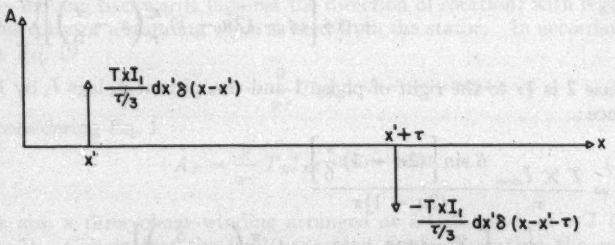


FIG. 6. Impulses of the linear current density.

cide with the "beginning" of phase 1 and will count the time from the moment the current I_1 in phase 1 reaches its maximum I_{max}

$$I_1 = I_{max} \operatorname{Re} e^{j\omega t}. \tag{13}$$

The $\frac{T \times I_1}{\tau/3} dx$ ampere-turns at $x = x'$ and $x = x' + \tau$ cause a linear current density shown in Fig. 6. It consists of two impulses of different signs and equal areas $\frac{T \times I_1}{\tau/3} dx'$. The Fourier series of these two impulses is

$$dA_1 = \sum_{n=1}^{\infty} \frac{T \times I_1}{\tau/3} dx' \frac{2}{\tau} \cos\left[(2n-1)\frac{\pi}{\tau}(x - x')\right] \tag{14}$$

and the linear current density of the phase 1 is

$$\begin{aligned} A_1 = \int_{x'=0}^{x'=\tau/3} dA_1 &= \frac{T \times I_{max}}{\tau/3} \frac{4}{(2n-1)\pi} \sin\left[(2n-1)\frac{\pi}{6}\right] \\ &\quad \times \cos \omega t \cos\left[(2n-1)\frac{\pi}{\tau}\left(x - \frac{\tau}{6}\right)\right] \\ &= \frac{T \times I_{max}}{\tau} \frac{6 \sin\left[(2n-1)\frac{\pi}{6}\right]}{(2n-1)\pi} \\ &\quad \times \left\{\cos\left[\omega t + (2n-1)\frac{\pi}{\tau}\left(x - \frac{\tau}{6}\right)\right]\right. \\ &\quad \left. + \cos\left[\omega t - (2n-1)\frac{\pi}{\tau}\left(x - \frac{\tau}{6}\right)\right]\right\}. \end{aligned} \tag{15}$$

Phase 2 is $\frac{2}{3}\tau$ to the right of phase 1 and the current I_2 lags I_1 by 120° hence:

$$\begin{aligned} A_2 = \frac{T \times I_{max}}{\tau} &\frac{6 \sin\left[(2n-1)\frac{\pi}{6}\right]}{(2n-1)\pi} \\ &\times \left\{\cos\left[\omega t - 120° + (2n-1)\frac{\pi}{\tau}\left(x - \frac{5}{6}\tau\right)\right]\right. \\ &\left. + \cos\left[\omega t - 120° - (2n-1)\frac{\pi}{\tau}\left(x - \frac{5}{6}\tau\right)\right]\right\}. \end{aligned} \tag{16}$$

Phase 3 is $\frac{4}{3}\tau$ to the right of phase 1 and its current I_3 lags I_1 by 240°—

$$A_3 = \frac{T \times I_{\max}}{\tau} \frac{6 \sin\left[(2n-1)\frac{\pi}{6}\right]}{(2n-1)\pi} \times \left\{\cos\left[\omega t - 240° + (2n-1)\frac{\pi}{\tau}\left(x - \frac{3}{2}\tau\right)\right] + \cos\left[\omega t - 240° - (2n-1)\frac{\pi}{\tau}\left(x - \frac{3}{2}\tau\right)\right]\right\}. \quad (17)$$

Summing up the last three equations, one obtains the total linear current density of the three-phase winding,

$$A = \frac{T \times I_{\max}}{\tau} \frac{18 \sin\left[(6n \pm 1)\frac{\pi}{6}\right]}{(6n \pm 1)\pi} \times \cos\left[\omega t \mp (6n \pm 1)\frac{\pi}{6}\left(x - \frac{\tau}{6}\right)\right] \quad n = 0, 1, 2, \cdots. \quad (18)$$

The first harmonic is

$$A = \frac{9}{\pi\tau} T I_{\max} \cos\left(\omega t - \frac{\pi}{\tau}x + \frac{\pi}{6}\right). \quad (19)$$

B represents a three-phase winding arranged at the pole pitch τ. The frequency of the voltages induced in B is (in cps.)

$$f_B = pn \quad (20)$$

where p is the number of pole pairs and n the rotor's speed in rps. The linear current density A_B associated with this winding constitutes a wave moving backwards (against the direction of rotation) with regard to the rotor or a standing wave as seen from the stator. In accordance with Eq. 19

$$A_B' = \bar{A}_B' e^{j\omega t} = \frac{9}{\pi\tau} T_B \bar{I}_B e^{-j[(\pi/\tau)x' - (\pi/6)]} e^{j\omega t} \quad (21)$$

or considering Eq. 1

$$A_B = \frac{9}{\pi\tau} T_B \bar{I}_B e^{-j[(\pi/\tau)x - (\pi/6)]}. \quad (22)$$

C is also a three-phase winding arranged at a pole pitch of $\tau/2$ (see Fig. 2). C is in fact the load connected across B so that the same current $\bar{I}_B$ flows through both windings B and C. The phase sequence of C differs from that of B (see Fig. 1) so that the linear current density A_C is

$$A_C' = \frac{9}{\pi\tau/2} T_C \bar{I}_B e^{j[2(\pi/\tau)x' - (\pi/6)]} e^{j\omega t} = \bar{A}_C' e^{j\omega t}. \quad (23)$$

The speed of this wave, as seen from the rotor, is

$$\frac{dx'}{dt} = -\frac{\omega\tau}{2\pi} = -f\tau = -\frac{n}{2}. \tag{24}$$

The $-$ sign here implies that this wave moves with the rotor, as we choose x to point against the direction of the machine's rotation. A_C moves therefore with regard to the stator at the speed

$$n + \frac{n}{2} = \frac{3}{2}n. \tag{25}$$

The D winding on the stator—arranged at a pole pitch $\tau/2$—will have induced voltages at the frequency

$$f_D = 2p \times \tfrac{3}{2}n = 3f. \tag{26}$$

This three-phase winding will have its "beginning" at $x = 0$ so that its linear current density will be

$$A_D' = \frac{18}{\pi\tau} T_D \bar{I}_D e^{j[2(\pi/\tau)x' - (\pi/6)]} e^{j\omega t}, \tag{27}$$

or in the stationary coordinate system

$$A_D = \frac{18}{\pi\tau} T_D \bar{I}_D e^{j[2(\pi/\tau)x - (\pi/6)]} e^{j3\omega t}. \tag{28}$$

7. SOLUTION OF THE DIFFERENTIAL EQUATION

The Laplace equation (9) of the electric rotational field in the air gap can be best solved in the rotating coordinate system $O'X'Y'$. The reason is that in this system all quantities involved seem to vary at the same frequency ω. The boundary conditions (10) and (11) and the explicit expressions of the linear current densities (12), (21), (23), (27) suggest a solution in the form

$$\bar{E}' = e^{-j(\pi/\tau)x'}(K_+ e^{(\pi/\tau)y'} + K_- e^{-(\pi/\tau)y'}) + e^{j2(\pi/\tau)x'}(C_+ e^{2(\pi/\tau)y'} + C_- e^{-2(\pi/\tau)y'}). \tag{29}$$

In accordance with Eq. 6 this leads to the following expression for $\bar{H}_z'$:

$$\bar{H}_z' = \frac{-\frac{\pi}{\tau}}{j\omega\mu_0} e^{-j(\pi/\tau)x'}(K_+ e^{(\pi/\tau)y'} - K_- e^{-(\pi/\tau)y'}) - \frac{2\frac{\pi}{\tau}}{j\omega\mu_0} e^{2j(\pi/\tau)x'}(C_+ e^{2(\pi/\tau)y'} - C_- e^{-2(\pi/\tau)y'}). \tag{30}$$

It is seen that we assumed the field to consist of two parts, one a wave moving in the positive x-direction and of length τ, the other a wave moving in the opposite direction and of length 2τ.

We assume windings A and B to consist of p pole pairs and C and D to consist of $2p$ pole pairs all connected in series. The induced emf.'s in the B, C and D windings add up at their terminals to the corresponding values (for phase 1)

$$\begin{aligned} E_B' &= pT_B \frac{2}{\tau/3} \int_{x'=0}^{x'=\tau/3} e^{j[\omega t-(\pi/\tau)x']}(K_+e^{(\pi/\tau)d} + K_-e^{-(\pi/\tau)d})\,dx' \\ &= pT_B \frac{6}{\pi}(K_+e^{(\pi/\tau)d} + K_-e^{-(\pi/\tau)d})e^{j[\omega t-(\pi/6)]}, \end{aligned} \tag{31}$$

$$\begin{aligned} E_C' &= 2pT_C \frac{2}{\tau/6} \int_{x'=0}^{x'=\tau/6} e^{j[\omega t+2(\pi/\tau)x']}(C_+e^{2(\pi/\tau)d} + C_-e^{-2(\pi/\tau)d})\,dx' \\ &= pT_C \frac{12}{\pi}(C_+e^{2(\pi/\tau)d} + C_-e^{-2(\pi/\tau)d})e^{j[\omega t+(\pi/6)]}, \end{aligned} \tag{32}$$

$$\begin{aligned} E_D &= 2pT_D \frac{2}{\tau/6} \int_{x=0}^{x=\tau/6} e^{j[3\omega t+2(\pi/\tau)x]}3(C_+ + C_-)\,dx \\ &= pT_D \frac{36}{\pi}(C_+ + C_-)e^{j[3\omega t+(\pi/6)]}. \end{aligned} \tag{33}$$

The factor of 3 is due to the triple frequency at which the field varies in the stationary coordinate system.

We shall neglect, at first, the ohmic resistance of the B and C windings. The total emf. induced in both windings B and C is zero

$$E_C' + E_B' = 0. \tag{34}$$

Inserting Eqs. 31, 32 into this last expression one obtains

$$\begin{aligned} &T_Be^{-j(\pi/6)}(K_+e^{(\pi/\tau)d} + K_-e^{-(\pi/\tau)d}) \\ &\qquad + 2T_Ce^{j(\pi/6)}(C_+e^{2(\pi/\tau)d} + C_-e^{-2(\pi/\tau)d}) = 0. \end{aligned} \tag{35}$$

We shall neglect also the resistance of the D winding and assume a load Z to be connected across the D terminals. From Eqs. 33 one deduces

$$pT_D \frac{36}{\pi}(C_+ + C_-)e^{j(\pi/6)} = \bar{I}_DZ. \tag{36}$$

From the boundary conditions (10) and (12), (27), (30) one obtains

$$\frac{-\frac{\pi}{\tau}}{j\omega\mu_0} e^{-j(\pi/\tau)x'}(K_+ - K_-) + \frac{2\frac{\pi}{\tau}}{j\omega\mu_0}(C_+ - C_-)e^{2j(\pi/\tau)x'}$$
$$= A_{A\max}e^{-j(\pi/\tau)x'} + \frac{18}{\pi\tau} T_D\bar{I}_D e^{j[2(\pi/\tau)x' - (\pi/6)]}$$

and hence

$$K_+ - K_- = j\omega\mu_0 \frac{\tau}{\pi} A_{A\max}, \tag{37}$$

$$C_+ - C_- = j\omega\mu_0 \frac{9}{\pi^2} T_D\bar{I}_D e^{-j(\pi/6)}. \tag{38}$$

Similarly from (10), (21), (23) and (30)—

$$\frac{-\frac{\pi}{\tau}}{j\omega\mu_0} e^{-j(\pi/\tau)x'}(K_+e^{(\pi/\tau)d} - K_-e^{-(\pi/\tau)d})$$
$$- \frac{2\frac{\pi}{\tau}}{j\omega\mu_0} e^{j2(\pi/\tau)x'}(C_+e^{2(\pi/\tau)d} - C_-e^{-2(\pi/\tau)d})$$
$$= \frac{9}{\pi\tau} T_B\bar{I}_B e^{-j[(\pi/\tau)x' - (\pi/6)]} + \frac{18}{\pi\tau} T_C\bar{I}_B e^{j[2(\pi/\tau)x' - (\pi/6)]} \tag{39}$$

and hence

$$K_+e^{(\pi/\tau)d} - K_-e^{-(\pi/\tau)d} = -j\omega\mu_0 \frac{9}{\pi^2} T_B\bar{I}_B e^{j(\pi/6)}, \tag{40}$$

$$C_+e^{2(\pi/\tau)d} - C_-e^{-2(\pi/\tau)d} = -j\omega\mu_0 \frac{9}{\pi^2} T_C\bar{I}_B e^{-j(\pi/6)}. \tag{41}$$

8. NO LOAD

The machine consists of two stages and two cases of no-load can be distinguished—one when $Z = \infty$ or the output current $\bar{I}_D$ vanishes, the other when the output current of the first stage $\bar{I}_B$ is zero. The second possibility is simpler to compute and will be discussed first. Equation 40 now takes on the form

$$K_+e^{(\pi/\tau)d} - K_-e^{-(\pi/\tau)d} = 0. \tag{42}$$

Last expression with (37) yields

$$K_+ = \frac{-j\omega\mu_0 \frac{\tau}{\pi} A_{A\max}}{2\sinh\frac{\pi}{\tau}d} e^{-(\pi/\tau)d}, \tag{43}$$

$$K_- = \frac{-j\omega\mu_0 \frac{\tau}{\pi} A_{A\max}}{2 \sinh \frac{\pi}{\tau} d} e^{(\pi/\tau)d}. \tag{44}$$

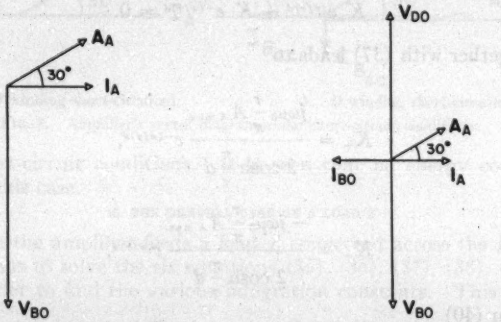
The voltage across the B terminals is in accordance with (31)

$$E_B' = -j\omega\mu_0 \frac{6\tau}{\pi^2} \frac{pT_B}{\sinh \frac{\pi}{\tau} d} A_{A\max} e^{j[\omega t - (\pi/6)]}. \tag{45}$$

It is seen that this no-load voltage lags the linear current density $\bar{A}$ by 120°, but in an equivalent three-phase system, $\bar{A}$ leads the current I, at $x' = 0$, by 30° (see Eq. 19) so that E_B' actually lags its magnetizing current by 90°, as was to be expected.

In case of the common no-load—$I_D = 0$ and Eq. 38 reads

$$C_+ - C_- = 0. \tag{46}$$



a. B terminals open-circuited. *b.* D terminals open-circuited.

FIG. 7. Vector diagrams for amplifier's operation at no-load.

From (37), (40), and (41) one obtains the values of the various constants K and C. Inserting back these values into (40), (31) and (33) one obtains the current and the voltages at no-load

$$\bar{I}_{BO}' = \frac{-\frac{\pi\tau}{18} \frac{T_B}{T_C^2} \tanh 2\frac{\pi}{\tau} d}{\sinh \frac{\pi}{\tau} d + \frac{1}{2}\left(\frac{T_B}{T_C}\right)^2 \tanh 2\frac{\pi}{\tau} d \cosh \frac{\pi}{\tau} d} \bar{A}_A e^{-j(\pi/6)}, \tag{47}$$

$$\bar{E}_B' = \frac{-j\omega\mu_0 \frac{6\tau}{\pi^2} pT_B}{\sinh \frac{\pi}{\tau} d + \frac{1}{2}\left(\frac{T_B}{T_C}\right)^2 \tanh 2\frac{\pi}{\tau} d \cosh \frac{\pi}{\tau} d} \bar{A}_A e^{-j(\pi/6)}, \tag{48}$$

$$\bar{E}_D = \frac{j\omega\mu_0 \frac{18\tau}{\pi^2} p \frac{T_B T_D}{T_C \cosh 2\frac{\pi}{\tau} d}}{\sinh \frac{\pi}{\tau} d + \frac{1}{2}\left(\frac{T_B}{T_C}\right)^2 \tanh 2\frac{\pi}{\tau} d \cosh \frac{\pi}{\tau} d} \bar{A}_A e^{-j(\pi/6)}. \quad (49)$$

Above results can be presented in vector diagrams shown in Fig. 7. It is clear that no energy transfer takes place in both above considered cases.

9. SHORT-CIRCUIT

Here, too, two cases are to be considered:

1. The B winding is short-circuited
2. The D terminals are short-circuited.

In case 1 the voltage $\bar{V}_B$ vanishes and Eq. 31 reads

$$K_+ e^{(\pi/\tau)d} + K_- e^{-(\pi/\tau)d} = 0. \quad (50)$$

This together with (37) leads to

$$K_+ = \frac{j\omega\mu_0 \frac{\tau}{\pi} A_{A\max}}{2\cosh \frac{\pi}{\tau} d} e^{-(\pi/\tau)d}, \quad (51)$$

$$K_- = \frac{-j\omega\mu_0 \frac{\tau}{\pi} A_{A\max}}{2\cosh \frac{\pi}{\tau} d} e^{(\pi/\tau)d}, \quad (52)$$

and from (40)

$$\bar{I}_{B_{s.c.}} = \frac{-\pi\tau\bar{A}_A}{9T_B \cosh \frac{\pi}{\tau} d} e^{-j(\pi/6)}. \quad (53)$$

In the second case $\bar{V}_D = 0$ which according to (33) means

$$C_+ + C_- = 0. \quad (54)$$

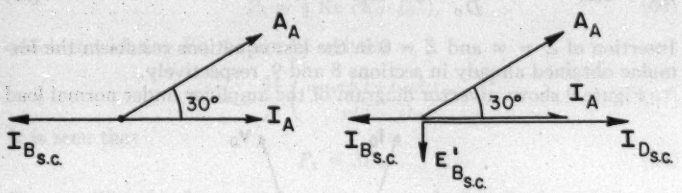
From Eqs. 37, 40 and 41 one obtains the constants K and C which inserted into (40), (38) and (31) yield the required currents and voltage

$$\bar{I}'_{B_{s.c.}} = \frac{-\frac{\pi\tau}{18}\frac{T_B}{T_C{}^2} \operatorname{ctgh} 2\frac{\pi}{\tau} d}{\sinh \frac{\pi}{\tau} d + \frac{1}{2}\left(\frac{T_B}{T_C}\right)^2 \operatorname{ctgh} 2\frac{\pi}{\tau} d \cosh \frac{\pi}{\tau} d} \bar{A}_A e^{-j(\pi/6)}, \quad (55)$$

$$\bar{I}_{D_{s.c.}} = \frac{\dfrac{\pi\tau}{18}\dfrac{T_B}{T_C T_D \sinh 2\dfrac{\pi}{\tau}d}}{\sinh\dfrac{\pi}{\tau}d + \dfrac{1}{2}\left(\dfrac{T_B}{T_C}\right)^2 \operatorname{ctgh} 2\dfrac{\pi}{\tau}d \cosh\dfrac{\pi}{\tau}d}\,\bar{A}_A e^{-j(\pi/6)}, \quad (56)$$

$$\bar{E}'_{B_{s.c.}} = \frac{-j\omega\mu_0\dfrac{6\tau}{\pi^2}pT_B}{\sinh\dfrac{\pi}{\tau}d + \dfrac{1}{2}\left(\dfrac{T_B}{T_C}\right)^2 \operatorname{ctgh} 2\dfrac{\pi}{\tau}d \cosh\dfrac{\pi}{\tau}d}\,\bar{A}_A e^{-j(\pi/6)}. \quad (57)$$

Above quantities are shown in Fig. 8 presenting the vector diagrams



a. *B* winding short-circuited. *b.* *D* winding short-circuited.

FIG. 8. Amplifier's vector diagram under short-circuit conditions.

under short-circuit conditions. It is seen that no energy conversion occurs in this case.

10. THE GENERAL CASE OF A LOAD *Z*

In case the amplifier feeds a load Z connected across the D terminals, one has to solve the six equations (35), (36), (37), (38), (40) and (41) in order to find the various integration constants. This leads to

$$C_+ = \frac{j\omega\mu_0\dfrac{\tau}{\pi}\dfrac{1}{4}\dfrac{T_B}{T_C}\left(1 + \dfrac{j\omega\mu_0 324 pT_D^2}{\pi^3 Z}\right)}{D_C}\,\bar{A}_A e^{-j(\pi/3)}, \quad (58)$$

$$C_- = \frac{j\omega\mu_0\dfrac{\tau}{\pi}\dfrac{1}{4}\dfrac{T_B}{T_C}\left(1 - \dfrac{j\omega\mu_0 324 pT_D^2}{\pi^3 Z}\right)}{D_C}\,\bar{A}_A e^{-j(\pi/3)}, \quad (59)$$

where

$$D_C = \sinh\frac{\pi}{\tau}d\cosh 2\frac{\pi}{\tau}d + \frac{1}{2}\left(\frac{T_B}{T_C}\right)^2\cosh\frac{\pi}{\tau}d\sinh 2\frac{\pi}{\tau}d + \frac{j\omega\mu_0 324 pT_D^2}{\pi^3 Z}\left[\sinh\frac{\pi}{\tau}d\sinh 2\frac{\pi}{\tau}d + \frac{1}{2}\left(\frac{T_B}{T_C}\right)^2\cosh\frac{\pi}{\tau}d\cosh 2\frac{\pi}{\tau}d\right]. \quad (60)$$

Equations 41, 32 and 36 now yield

$$\bar{I}_B = \frac{-\frac{\pi\tau}{18}\frac{T_B}{T_C{}^2}\left(\sinh 2\frac{\pi}{\tau}d + \frac{j\omega\mu_0 324 p T_D{}^2}{\pi^3 Z}\cosh 2\frac{\pi}{\tau}d\right)}{D_C}\bar{A}_A e^{-j(\pi/6)}, \quad (61)$$

$$\bar{E}_B{}' = -\bar{E}_C{}'$$

$$= \frac{-j\omega\mu_0\frac{6\tau}{\pi^2}pT_B\left(\cosh 2\frac{\pi}{\tau}d + \frac{j\omega\mu_0 324 p T_D{}^2}{\pi^3 Z}\sinh 2\frac{\pi}{\tau}d\right)}{D_C} \times \bar{A}_A e^{-j(\pi/6)}, \quad (62)$$

$$\bar{E}_D{}' = \bar{I}_D Z = \frac{j\omega\mu_0\frac{18\tau}{\pi^2}p\frac{T_B T_D}{T_C}}{D_C}\bar{A}_A e^{-j(\pi/6)}. \quad (63)$$

Insertion of $Z = \infty$ and $Z = 0$ in the last equations results in the formulae obtained already in sections 8 and 9, respectively.

Figure 9 shows a vector diagram of the amplifier under normal load

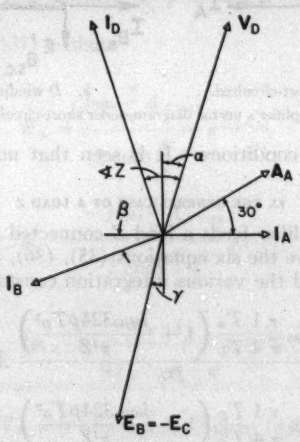


FIG. 9. Amplifier's vector diagram under normal conditions.

conditions. It represents the phasors given by the last three expressions. The angles α, β and γ appearing in this figure can be easily computed.

11. ENERGY CONVERSION

This occurs at both stages and the amplification factor is to be derived therefrom. At both stages electrical power is fed into the exciting winding (A and C, respectively) and taken from the armature winding

(B or D) while the amplification is due to the mechanical power supplied to the rotor.

The power P_1 delivered by the first amplification stage is (per phase)

$$P_1 = \tfrac{1}{2} \operatorname{Re} (\bar{E}_B \cdot \bar{I}_B^*) \tag{64}$$

where $\bar{I}_B^*$ is the conjugate value of the phasor $\bar{I}_B$. Inserting the values of $\bar{E}_B$ and $\bar{I}_B$ from (61) and (62) one obtains

$$P_1 = \frac{54}{Z} \left(\frac{\omega \mu_0 \tau p T_B T_D A_{A\max}}{\pi^2 T_C |D_C|} \right)^2. \tag{65}$$

The power output of the second stage P_2 is similarly

$$P_2 = \tfrac{1}{2} \operatorname{Re} (\bar{E}_D \cdot \bar{I}_D^*), \tag{66}$$

which considering Eq. 63 can be written as

$$P_2 = 3 \frac{54}{Z} \left(\frac{\omega \mu_0 \tau p T_B T_D A_{A\max}}{\pi^2 T_C |D_C|} \right)^2. \tag{67}$$

It is seen that

$$P_2 = 3P_1. \tag{68}$$

The amplification factor of the second stage is 3 while that of the first stage is ∞ unless we consider the resistance of the A winding.

12. THE ACTUAL MACHINE

In the previous sections we developed the theory of our idealized two-stage amplifier. The main discrepancy between the model, shown in Fig. 3, and an actual machine lies in the assumption of infinitesimally thin current carrying sheets, that we assumed on the stator and rotor surfaces. In actual practice, both the stator and rotor windings are to be accommodated in stator and rotor slots, respectively. The permeability of the stator and rotor yokes could still be considered infinite while that of the stator and rotor teeth is to be taken as finite due to high magnetic flux densities in this region. Instead of solving the field equations in the air gap only one would have to consider Maxwell's field equations in the air gap and stator and rotor teeth and slots regions. The ends effect cannot be neglected as the greatest part of the leakage inductance is usually associated with that part of the conductors connecting the various slots in the overhang region. The electro-magnetic field in that region and the energies stored there have to be fully counted with if good numerical results are required.[3]

Alternatively one could extend the vector diagram, shown in Fig. 9. We shall distinguish, now, between the emf.'s induced by the main fluxes and those due to the leakage fluxes and we will consider the volt-

[3] See E. MISHKIN, "Theory of the Induction Machine Derived Directly from Maxwell's Field Equations," *Quart. J. Mech. Appl. Math.*, Vol. VII, Part 4, December 1954.

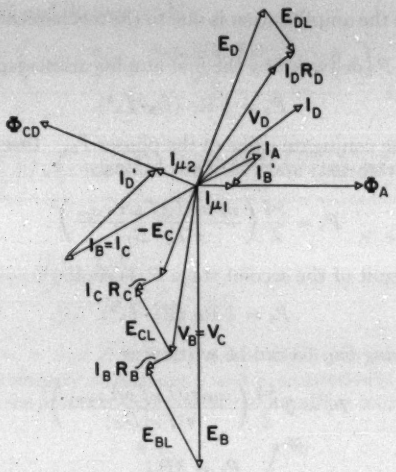


FIG. 10. Vector diagram of a non-idealized machine under normal load conditions.

age drops in the individual windings due to their finite ohmic resistances. Figure 10 shows such a vector diagram referred to the rotating coordinate system where all phasors vary synchronously. (The apostrophe sign is omitted on all the phasors.) Here—

R_{A1}, R_{B1}, R_{C1}, R_D are the resistances of the windings A_1, B_1, C and D, respectively
$\bar{I}_B'$—current in the B winding referred to the A winding
$\bar{I}_D'$—current in the D winding referred to the C winding
Φ_{AB}—magnetic flux due to the currents I_A and I_B
Φ_{CD}—magnetic flux due to the currents I_C and I_D
$\bar{I}_{\mu 1}$, $\bar{I}_{\mu 2}$—magnetizing currents of fluxes Φ_{AB} and Φ_{CD}, respectively
$\bar{E}_B$—emf. induced in winding B by flux Φ_{AB}
$\bar{E}_C$, $\bar{E}_D$—emf.'s induced by flux Φ_{CD} in windings C and D, respectively
$\bar{E}_{BL}$, $\bar{E}_{CL}$, $\bar{E}_{DL}$—emf.'s in windings B, C, D caused by their leakage reactances (fluxes)
$\bar{E}_B = \bar{E}_C$—input voltage of B winding = voltage applied to the C winding
$\bar{E}_D$—amplifier's output voltage (winding D).

The various leakage reactances, magnetizing currents, etc., are to be computed in the same way as it is being done for ordinary induction machines.

It is obvious that the information given here in form of vector diagrams could also be presented in form of equivalent circuit diagrams or block diagrams—these being only different in form.

SOME ELECTROMAGNETIC PARADOXES

BY

PARRY MOON [1] AND DOMINA EBERLE SPENCER [2]

1. INTRODUCTION

Electromagnetic theory is undoubtedly one of the most imposing theoretical edifices reared by the mind of man. It is a work of genius—of Maxwell, Hertz, Lorenz, Lorentz, Poincaré, Einstein. Yet it does not form a logical whole, as evidenced by numerous paradoxes.

Classical theory is built up of pieces, each admirable in its way but not fitting too comfortably into the whole. Sometimes we pretend that flux lines have physical existence: we visualize them as rubber bands pulling on conductors or as filaments that are cut by moving wires. At other times we are unable to decide whether these flux lines are moving or stationary, and we fall back on Maxwell's equations which express the phenomena in terms of the rather abstract vectors **E**, **D**, **B**, **H**. At still other times, we find it desirable to use retarded potentials. Einstein's relativity may also be introduced.

Unfortunately, these various methods of handling a problem do not always lead to the same conclusion. Hence the paradoxes! If one knows the correct result, he can usually find a part of classical theory that will give him the answer. And he can always justify his choice by some plausible argument. But an equally logical argument can be found for other approaches that may give erroneous results. As Ko-Ko says, "Here's a state of things, here's a how-de-do!"

In the following pages, we consider a number of paradoxes. In each case, the problem is stated and a solution is given. This solution is in accordance with classical theory but does not agree with experiment. It is the kind of solution that might be obtained by a scrupulous but inexperienced student. The reader may amuse himself by finding a classical approach that gives the correct answer.

Each problem is also solved by employing the interparticle method developed by Coulomb, Ampère, Gauss, and Ritz. This method, unlike the Maxwell formulation, can be summarized (1)[3] in *a single equation and this equation gives unambiguous results*. In the new electrodynamics, no paradoxes have been found.

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[1] Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[2] Department of Mathematics, University of Connecticut, Storrs, Conn.

[3] The boldface numbers in parentheses refer to the references appended to this paper.

2. THE NEW ELECTRODYNAMICS

The non-Maxwellian approach subsumes the whole of electrodynamics under the single equation,

$$\mathbf{F}_2/Q_2 = \mathbf{a}_r \frac{Q_1}{4\pi\epsilon c^2 r^2}\left[\mathbf{v}\cdot\mathbf{v} - \tfrac{3}{2}(\mathbf{a}_r\cdot\mathbf{v})^2\right] - \frac{Q_1}{4\pi\epsilon c^2 r}\frac{d}{dt}\mathbf{v}(t - r/c) - \mathbf{a}_r \frac{1}{4\pi\epsilon}\frac{\partial}{\partial r}\left[\frac{1}{r}Q_1(t - r/c)\right]. \quad (1)$$

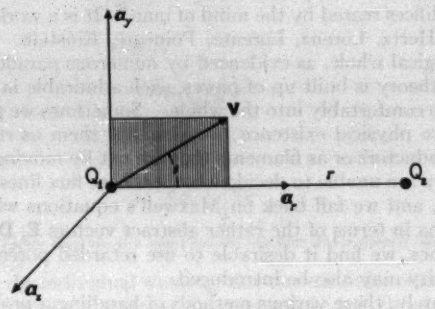

FIG. 1. Two charged particles.

The notation is indicated in Fig. 1. The unit vector $\mathbf{a}_r$ points from Q_1 to Q_2. Angles are measured counter-clockwise from $\mathbf{a}_r$. Vector $\mathbf{v}$ is the *relative velocity of* Q_1 *with respect to* Q_2. Equation 1 applies at all ordinary velocities: in fact, it is reasonably accurate up to approximately half the velocity of light. At higher velocities, corrections must be applied.

Note that the magnetic-field concept is completely eliminated and $\mathbf{B}$, $\mathbf{H}$, and μ do not occur. The usual "magnetic" forces and "flux-cutting emf.'s" are handled by the first term of Eq. 1 which depends on the *relative velocity* of charges. The second term depends on the *acceleration* of charges, while the third term is related to Maxwell's displacement current and includes the Coulomb force as a special case (1). For moderate frequencies and distances, retardation may be neglected and Eq. 1 reduces to

$$\mathbf{F}/Q_2 = \mathbf{a}_r \frac{Q_1}{4\pi\epsilon r^2}\left(\frac{v}{c}\right)^2\left[1 - \tfrac{3}{2}\cos^2\theta\right] - \mathbf{a}_a \frac{Q_1}{4\pi\epsilon c^2 r}\frac{dv}{dt} + \mathbf{a}_r \frac{Q_1}{4\pi\epsilon r^2}. \quad (1a)$$

Equations 1 and 1*a* apply to the force between charges Q_1 and Q_2, Fig. 1. These equations are easily extended (1) to give the force be-

tween current elements or between a current element and a charge. For a current element $I_1 d\mathbf{s}_1$ and a charge Q_2 (Fig. 2), the first term of Eq. 1 gives

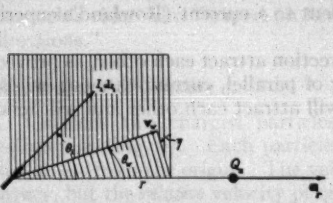

FIG. 2. Current element and charged particle.

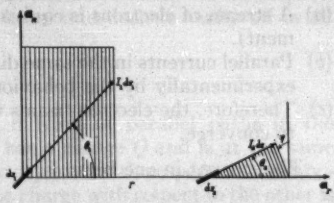

FIG. 3. Two current elements.

$$d\mathbf{F}/Q_2 = \mathbf{a}_r \frac{|I_1|}{4\pi\epsilon c^2 r^2}\left[2(\mathbf{a}_r \times \mathbf{v}_w)\cdot(\mathbf{a}_r \times d\mathbf{s}_1) - (\mathbf{a}_r\cdot\mathbf{v}_w)(\mathbf{a}_r\cdot d\mathbf{s}_1)\right]$$

$$= \mathbf{a}_r \frac{|I_1| v_w ds_1}{4\pi\epsilon c^2 r^2}\left[2\sin\theta_w \sin\theta_1 \cos\eta - \cos\theta_w \cos\theta_1\right]. \qquad (2)$$

Here the sense of $d\mathbf{s}_1$ is the direction of the current, and $\mathbf{v}_w$ is the velocity of the material wire with respect to Q_2. Equation 1 also yields a term directly proportional to the drift velocity $\mathbf{v}_1$ of the electrons (2). Apparently, this additional force is always too small to be measured, so it will be ignored in this paper.

The first term of Eq. 1 can be applied also to two current elements (Fig. 3). This Ampère force is

$$d^2\mathbf{F} = -\mathbf{a}_r \frac{|I_1||I_2|}{4\pi\epsilon c^2 r^2}\left[2(\mathbf{a}_r \times d\mathbf{s}_1)\cdot(\mathbf{a}_r \times d\mathbf{s}_2) - (\mathbf{a}_r\cdot d\mathbf{s}_1)(\mathbf{a}_r\cdot d\mathbf{s}_2)\right]. \qquad (3)$$

This force is independent of the relative velocity of the material elements. Equation 3 is a rigorous deduction from the first part of Eq. 1, with no terms neglected.

The remainder of the paper is devoted to a consideration of a few of the paradoxes that occur in conventional electromagnetic theory.

3. ELECTRON BEAMS

Statement

Parallel electron guns produce two identical electron beams in a long, evacuated tube. Initial velocity of the electrons with respect to the laboratory is $\mathbf{v}_0$. What is the magnitude and direction of the force on the electrons?

A Classical Solution

The argument may be stated rather neatly in the form of a classical syllogism:

(*a*) A stream of electrons is equivalent to a current (Rowland's experiment).
(*b*) Parallel currents in the same direction attract each other, as proved experimentally by the behavior of parallel, current-carrying wires.
(*c*) Therefore, the electron beams will attract each other and will tend to converge.

The current in one beam is

$$I = - NA|Q_e|v,$$

where

N = number of free electrons per unit volume,
A = cross-sectional area of the beam,
$|Q_e|$ = magnitude of electronic charge.

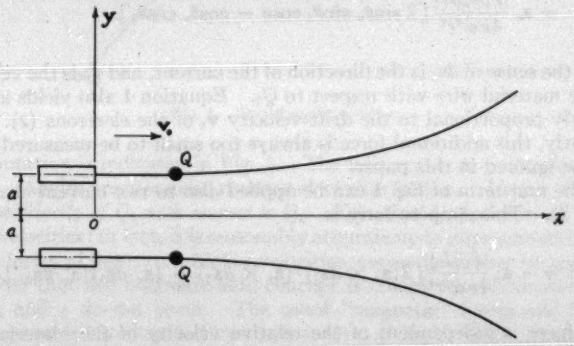

FIG. 4. Electron beams. Electrons are emitted at $x = 0$ with velocity v_0 in the x-direction.

This current produces a magnetic flux density at the other beam,

$$B = \frac{\mu_0 I}{2\pi a},$$

where a is the distance between the axes of the beams. The resulting force per unit length is

$$F/l = BI = \frac{\mu_0 I^2}{2\pi a} = \frac{N^2 A^2 |Q_e|^2}{2\pi\epsilon c^2 a} v^2. \qquad (4)$$

The force is perpendicular to $\mathbf{v}$ and tends to pull the beams together; a result that is certainly not in accord with experiment.

For other solutions, the reader is referred to *Electrical Engineering* (3), where a long and inconclusive discussion reminds one of Stephen Leacock's rider who "leaped on his horse and dashed madly off in all directions."

Electrodynamic Solution

Consider two charged particles moving in parallel paths in the x-direction (Fig. 4). Each particle has a charge Q and is at the same distance x from the origin. The velocity is $\mathbf{v}_0$ with respect to the laboratory, but the *relative* velocity of one charge with respect to the other is zero. Thus Eq. 1 reduces to the Coulomb equation, and the force on the upper particle is

$$\mathbf{F} = \mathbf{a}_r \frac{Q^2}{4\pi\epsilon r^2}. \tag{5}$$

For a coordinate system moving with the charges, *the force is an ordinary electrostatic repulsion which is exactly the same as if the charges were stationary*. The electron beams of Fig. 4 will therefore tend to diverge, as found in practice.

The force, Eq. 5, will accelerate the particles in the y-direction:

$$F = m \frac{d^2y}{dt^2}$$

or

$$y = a + \frac{F}{m} t^2.$$

But $x = v_0 t$; so the path of the upper particle referred to a stationary coordinate system, is a parabola:

$$y = a + (F/mv_0^2)x^2. \tag{6}$$

Thus the problem is a very simple one, requiring only a knowledge of elementary mechanics and of Coulomb's equation. Classical treatment, on the other hand, introduces puzzling questions such as the presence or absence of a magnetic field, depending on the motion of the observer. Such questions do not arise in the new electrodynamics, nor is Einstein's relativity needed.

Equations 1 and 6 do not apply for $v \to c$ without additional correction terms. Strictly speaking, corrections should be made also for the velocity and acceleration in the y-direction. This modification is easily accomplished by use of the first and second terms of Eq. 1; but since both terms include c^2 in the denominator, their effect is ordinarily

negligible. For the electron-beam problem, the Coulomb repulsions of all electrons in the beams should be considered. But this would not change the foregoing general conclusion that *the force is merely a Coulomb repulsion and is never the attraction obtained with parallel currents.*

4. LONGITUDINAL MOTION

Statement

A flexible conductor AA', Fig. 5, carries a direct current I_1. Near A is a long, straight conductor C carrying a steady current I_2. The

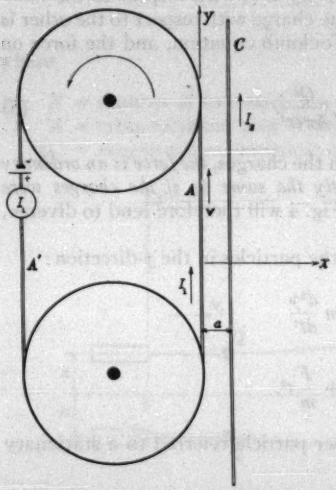

FIG. 5. Determine the force between conductors A and C when A is in uniform longitudinal motion.

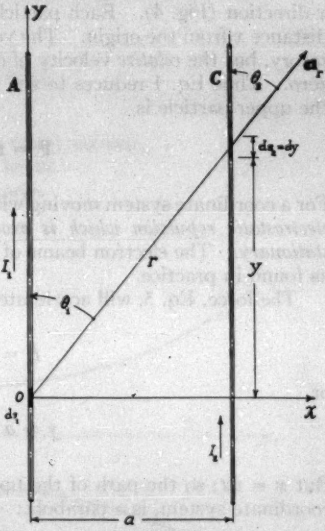

FIG. 6. Analysis of Fig. 5.

distance a is small compared with the other dimensions, so the effects of the return conductors may be neglected. What is the force per unit length, exerted on conductor C?

A Classical Solution

First consider AA' stationary. The magnetic flux density at C, caused by current I_1, is

$$B = \frac{\mu_0 I_1}{2\pi a}.$$

The force on C, according to Faraday's relation, is

$$F_2 = BlI_2$$

or

$$F_2/l = \frac{\mu_0 I_1 I_2}{2\pi a} = \frac{I_1 I_2}{2\pi\epsilon c^2 a}. \tag{7}$$

The current in A is

$$I_1 = N_1 A_1 |Q_e| v_1,$$

where the symbols are as in Section 3 and v_1 is the magnitude of the drift velocity of the electrons in A.

Now allow A to move longitudinally at velocity $\mathbf{v}$. According to Rowland's experiment, moving charges constitute a current, so the *effective* current is not I_1 but is

$$I_1' = N_1 A_1 |Q_e| (v_1 - v)$$
$$= I_1 \left(\frac{v_1 - v}{v_1} \right).$$

Replacing I_1 in Eq. 7 by I_1', we obtain

$$F_2/l = \frac{I_1 I_2}{2\pi\epsilon c^2 a} \left(\frac{v_1 - v}{v_1} \right). \tag{8}$$

Since v may easily exceed $10^4 v_1$, we can obtain with the moving conductor a force 10,000 times as great as that obtained with the stationary conductor. What is wrong with this prediction?

Electrodynamic Solution

It is easily proved that Eq. 3 is independent of conductor velocity. Thus the force is independent of $\mathbf{v}$ and is obtained by integration of Eq. 3. From Fig. 6, $\theta_1 = \theta_2 = \theta$, $\eta = 0$, and the force on element ds_2 is

$$d\mathbf{F}_2 = -\mathbf{a}_x \frac{|I_1||I_2|ds_2}{4\pi\epsilon c^2} \int_{-\infty}^{\infty} \frac{[2\sin^2\theta - \cos^2\theta]\sin\theta}{r^2}\, dy$$

$$= \mathbf{a}_x \frac{|I_1||I_2|ds_2}{2\pi\epsilon c^2 a}.$$

The force is independent of the position of ds_2 in the y-direction, so the force per unit length on C is

$$\mathbf{F}_2/l = \mathbf{a}_x \frac{|I_1||I_2|}{2\pi\epsilon c^2 a}, \tag{9}$$

which agrees with Eq. 7.

The only difference between the classical and the electrodynamic solution is that Eq. 7 may leave one with doubts as to possible effects of the motion of the conductor, while Eq. 1 leads directly and conclusively to Eq. 9, *irrespective of longitudinal motion.*

5. INDUCED EMF.

Statement

A moving conductor AA', Fig. 7, carries a steady current I_1. A wire W is provided with ballistic galvanometer G and switch S. When

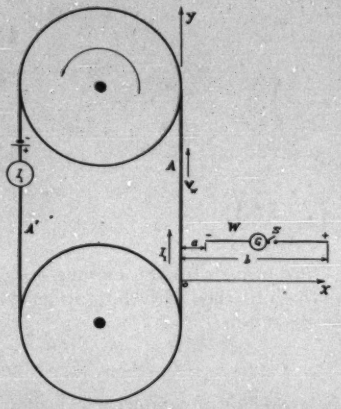

FIG. 7. Determine the induced emf. in W, caused by the longitudinal motion of conductor A.

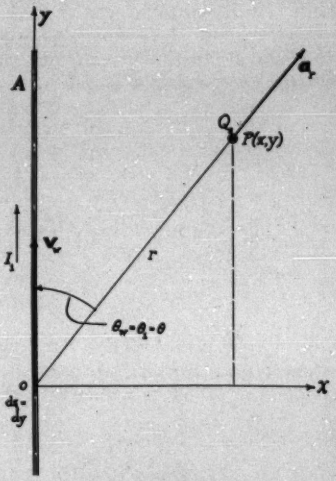

FIG. 8. Analysis of Fig. 7.

A is in uniform motion, S is closed. If an emf. is induced, there will be a momentary deflection of G. Is there an induced emf. in W?

A Classical Solution

At a given distance x from conductor A, the magnetic flux density is constant, independent of y. Thus the vectors $\mathbf{B}$ along W are independent of time, irrespective of the motion of A. Consequently $\partial \mathbf{B}/\partial t = 0$ and there can be no induced emf., either by transformer action or by flux cutting. This conclusion is also in accordance with Faraday's idea that flux lines are not dragged along by the longitudinal motion of a conductor.

Electrodynamic Solution

The force per unit charge at a point (x,y), Fig. 8, is obtained by using Eq. 2:

$$d\mathbf{F}_2/Q_2 = \mathbf{a}_r \frac{|I_1|v_w ds_1}{4\pi\epsilon c^2 r^2}[2\sin^2\theta - \cos^2\theta].$$

The total effect of conductor A is obtained by integration. The y-component of $\mathbf{F}_2$ is zero, leaving

$$\mathfrak{F}_x = F_x/Q_2 = \frac{|I_1|v_w}{4\pi\epsilon c^2}\int_{-\infty}^{\infty}[2\sin^2\theta - \cos^2\theta]\sin\theta\frac{dy}{r^2}$$

$$= \frac{|I_1|v_w}{2\pi\epsilon c^2 x}. \tag{10}$$

The emf. induced in W is therefore

$$V = \int_a^b \mathfrak{F}_x dx = \frac{|I_1|v_w}{2\pi\epsilon c^2}\ln(b/a), \tag{11}$$

which is certainly not zero as predicted by the foregoing classical theory.

6. MOVING BRIDGE

Statement

A metal bridge A floats in two mercury troughs H and H' (Fig. 9). The circuit carries a direct current I. In what direction will the bridge move? This is one of Carl Hering's celebrated experiments (4).

A Classical Solution

It is a well-known experimental fact that a circuit carrying a current tends to expand. For instance, a loop of flexible wire will tend to assume a circular form as the result of electromagnetic forces. In accordance with this principle, *the bridge will move to the right.*

To check this conclusion, consider the direction of the magnetic vector **B**. With current as shown in Fig. 9, the entire circuit produces within the loop a magnetic flux that is perpendicular to the diagram and directed into the paper. The force on the bridge is given by the firmly established relation,

$$\mathbf{F} = I\boldsymbol{l} \times \mathbf{B}.$$

But if **I** in the bridge is downward and **B** is into the paper, **F** *must be to the right for any position of the bridge.* This conclusion does not agree with experiment.

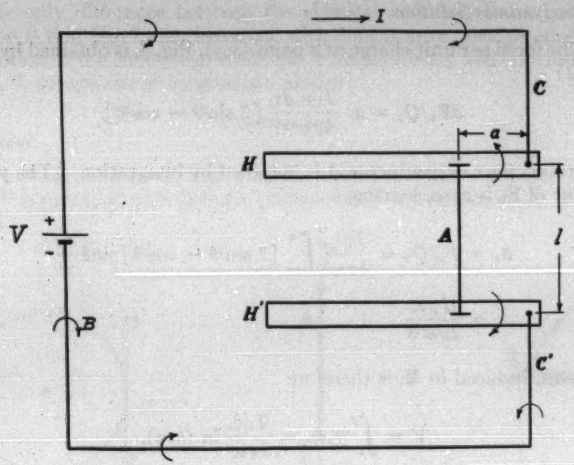

FIG. 9. Motion of metal bridge A floating on mercury troughs H, H'.

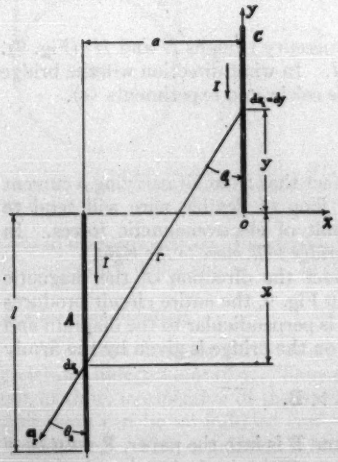

FIG. 10a. Analysis of forces caused by conductor C, Fig. 9.

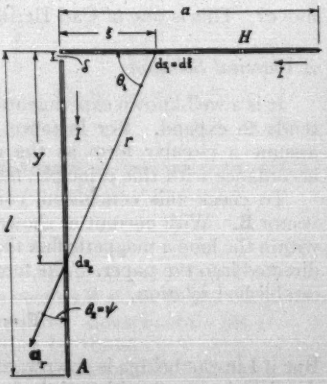

FIG. 10b. Analysis of forces caused by conductor H, Fig. 9.

Electrodynamic Solution

The solution requires merely the integration of Eq. 3 around the circuit. This integration is not troublesome in any case, but the ideas can be presented most simply by letting the left part of the circuit expand until its effect on A is negligible. We need consider then only the forces caused by two long vertical conductors C and C' and by the portions of the mercury that are carrying current.

For the conductor C, Fig. 10*a*, $\eta = 0$ and $\theta_1 = \theta_2 = \theta$, so Eq. 3 becomes

$$d^2\mathbf{F}_2 = -\mathbf{a}_r \frac{I^2 ds_1 ds_2}{4\pi\epsilon c^2 r^2}[2\sin^2\theta - \cos^2\theta].$$

The force contains both x and y components, but integration over equal, long conductors C and C' will cancel the y-component. Thus the total force on $d\mathbf{s}_2$, caused by conductor C, is

$$d\mathbf{F}_2 = \mathbf{a}_x \frac{I^2 ds_2}{4\pi\epsilon c^2}\int_0^\infty \frac{2a^2 - a(y + y_0)^2}{r^5}\,dy$$

$$= \mathbf{a}_x \frac{I^2 ds_2}{4\pi\epsilon c^2 a}\left[1 - \frac{y_0^3 + 2y_0a^2}{(a^2 + y_0^2)^{\frac{3}{2}}}\right].$$

The force on the bridge, caused by current in C and C', is

$$\mathbf{F}_2 = \mathbf{a}_x \frac{I^2}{2\pi\epsilon c^2 a}\int_0^l \left[1 - \frac{y_0^3 + 2y_0a^2}{(a^2 + y_0^2)^{\frac{3}{2}}}\right] dy_0$$

$$= \mathbf{a}_x \frac{I^2}{2\pi\epsilon c^2 \lambda}\left[1 - \frac{1}{(1 + \lambda^2)^{\frac{1}{2}}}\right], \tag{12}$$

where $\lambda = a/l$. *This force on the bridge is in the positive x-direction and tends to pull the conductor to an equilibrium position at* $x = 0$.

Equation 12 applies only to the effect of conductors C and C'. Now take a mercury trough, Fig. 10*b*. Let $\eta = 0, \theta_2 = \psi, \theta_1 = -(\pi/2 - \psi)$. Then Eq. 3 becomes

$$d^2\mathbf{F}_2 = \mathbf{a}_r \frac{3I^2 ds_1 ds_2}{4\pi\epsilon c^2 r^2}\sin\psi\cos\psi.$$

Evidently the y-components for H and H' will cancel, leaving only

$$d^2\mathbf{F}_2 = -\mathbf{a}_r \frac{3I^2 ds_1 ds_2}{4\pi\epsilon c^2 r^2}\sin^2\psi\cos\psi.$$

The force on ds_2, caused by H, is

$$d\mathbf{F}_2 = -\mathbf{a}_x \frac{3I^2 ds_2}{4\pi\epsilon c^2} \int_0^a \frac{y\xi^2}{r^5}\, d\xi$$

$$= -\mathbf{a}_x \frac{I^2 ds_2}{4\pi\epsilon c^2} \frac{a^3}{y(y^2 + a^2)^{\frac{1}{2}}}.$$

The total force on the bridge, produced by current in H and H', is therefore

$$\mathbf{F}_2 = -\mathbf{a}_x \frac{I^2 a^3}{2\pi\epsilon c^2} \int_\delta^l \frac{dy}{y(y^2 + a^2)^{\frac{1}{2}}}.$$

Since $\delta \ll a$,

$$\mathbf{F}_2 \cong -\mathbf{a}_x \frac{I^2}{2\pi\epsilon c^2}\left[\ln\left(\frac{2a}{\delta}\frac{1}{\lambda + (1+\lambda^2)^{\frac{1}{2}}}\right) - \left(1 - \frac{\lambda}{(1+\lambda^2)^{\frac{1}{2}}}\right)\right]. \quad (13)$$

The force caused by current in the mercury elements is always in the negative x-direction. The value of the bracket in Eq. 13 is generally in the neighborhood of $+3$ or $+4$. The exact value depends on detailed conditions at the right-angled corners, an analysis of which is not needed here.

The total force on the bridge is expressed as the sum of Eqs. 12 and 13, or

$$\mathbf{F}_2 = -\mathbf{a}_x \frac{I^2}{2\pi\epsilon c^2}\left\{\ln\left(\frac{2a}{\delta}\frac{1}{\lambda + (1+\lambda^2)^{\frac{1}{2}}}\right) - \frac{1}{\lambda}[1 + \lambda - (1+\lambda^2)^{\frac{1}{2}}]\right\}. \quad (14)$$

For comparatively small displacements a, the first term of Eq. 14 predominates and the bridge moves to the left, as found experimentally by Hering (4). But for large displacements, the bridge may move to the right until it reaches an equilibrium position determined by the relation,

$$\ln\left(\frac{2a}{\delta}\frac{1}{\lambda + (1+\lambda^2)^{\frac{1}{2}}}\right) = \frac{1}{\lambda}[1 + \lambda - (1+\lambda^2)^{\frac{1}{2}}]. \quad (15)$$

For instance, if the logarithm has the value 4, then

$$4\lambda = 1 + \lambda - (1+\lambda^2)^{\frac{1}{2}}$$

or

$$\lambda = a/l = \tfrac{3}{4}.$$

Thus, in this example, the bridge will move to the left until its displace-

ment is $\frac{3}{4}$ of its length. The bridge will remain in this equilibrium position.

7. UNIPOLAR GENERATOR

Statement

A copper disk D (Fig. 11) rotates on its axis A at uniform angular velocity Ω. Direct current I_1 in a stationary loop W produces a mag-

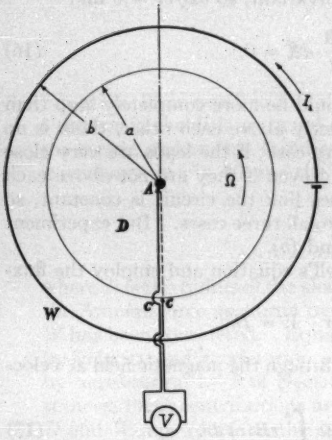

FIG. 11. Unipolar generator. Magnetic field produced by direct current in loop W; voltage is generated by rotation of disk D.

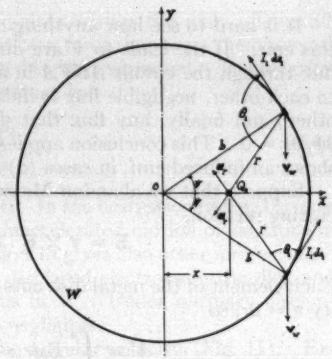

FIG. 12. Analysis of Fig. 11.

netic field. Contact is made to the disk at A and C, and a bifilar conductor connects these brushes to an electrostatic voltmeter V.

(*a*) What is the emf. indicated by the voltmeter?
(*b*) If D and W now rotate in the same direction and at the same angular velocity, what is the emf.?
(*c*) The disk and voltmeter are stationary and only W rotates. What is the emf.?

A Classical Solution

Start with Maxwell's equation,

$$\text{curl } \mathbf{E} = -\,\partial \mathbf{B}/\partial t,$$

which is regarded as a cornerstone of electromagnetics, true under all

circumstances. Integration over *any closed path* L enclosing an area $\mathfrak{a}$ gives

$$\int_{\mathfrak{a}} \text{curl } \mathbf{E} \cdot d\mathfrak{A} = \oint_L \mathbf{E} \cdot d\mathbf{s} = V = -\int_{\mathfrak{a}} \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathfrak{A}.$$

For our closed path, we choose the dotted line AC in the disk and the fixed metallic circuit CVA. But the flux density $\mathbf{B}$, produced by the steady current I_1, is certainly time-invariant, so $\partial \mathbf{B}/\partial t = 0$ and

$$V = -\int_{\mathfrak{a}} \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathfrak{A} = 0. \tag{16}$$

It is hard to see how anything could be more completely zero than this emf. If the leads to V are directly above each other, there is no flux through the circuit $ACVA$ in any case; if the leads are very close to each other, negligible flux is linked even if they are not above each other; and finally, any flux that does link the circuit is constant, so $\partial \Phi/\partial t = 0$. This conclusion applies to all three cases. But experiment shows an induced emf. in cases (*a*) and (*b*).

Suppose that we abandon Maxwell's equation and employ the flux-cutting relation,

$$\mathbf{E} = \mathbf{v} \times \mathbf{B} \quad \text{or} \quad V = Blv.$$

Each element of the metal disk cuts through the magnetic field at velocity $v = \Omega r$, so

$$V = \int_0^a E_r dr = \Omega \int_0^a rB(r)\, dr. \tag{17}$$

Equation 17 gives the same emf. as that produced by a radial wire, and this result agrees with experiment for case (*a*).

In (*b*), however, there is no relative motion between wire and disk, so there is no flux cutting and $V = 0$. Experiment shows, however, that the emf. is the same as in (*a*). In (*c*), there is again relative motion between the wire and the disk, so the emf. should be given by Eq. 17. Actually, there is no emf.

Electrodynamic Solution

Equation 2 expresses the force per unit charge acting at any point in the disk because of a current element in W. It is convenient to take the elements in pairs at $\pm\psi$ as shown in Fig. 12. Each element produces a force in the direction of its $\mathbf{a}_r$. The y-components cancel, leaving only an x-component:

$$d\mathfrak{F} = -\mathbf{a}_x \frac{|I_1| v_w}{2\pi\epsilon c^2} \frac{bd\psi}{r^4} [bx \cos^2\psi + 3bx - 2(b^2 + x^2)\cos\psi](b\cos\psi - x).$$

So at any point in the disk, *electrons are acted on by a radial force.*

(*a*) Integration from 0 to π gives the effect of the complete current loop:

$$\mathfrak{F} = \mathbf{a}_x \frac{|I_1| v_w}{2\pi\epsilon c^2}\left[\frac{E(k)}{b-x} + \frac{K(k)}{b+x}\right], \tag{18}$$

where E and K are complete elliptic integrals of modulus

$$k = \frac{2(bx)^{\frac{1}{2}}}{b+x}.$$

Equation 18 is positive for all points within the disk. Thus all electrons in the disk are acted on by a force that urges them toward the center, and an emf. is indicated by the voltmeter. The polarity is as shown in Fig. 11 and the voltage is

$$V = \int_R^a \mathfrak{F} dr, \tag{19}$$

where R is the radius of the shaft. In the derivation of Eq. 18, only the Ampère force produced by unaccelerated motion of electrons in W has been considered. Equation 1*a* gives also other forces caused by velocity and acceleration of displaced electrons in the disk and by acceleration v_1^2/b of electrons in W. Under ordinary circumstances, these contributions are negligible.

(*b*) D and W now rotate at the same angular velocity (Fig. 11). Except for negligible velocity and acceleration terms, the emf. induced in the disk is zero in accordance with Eq. 18. The emf. induced in the bifilar conductor CV is also zero. But the conductor AC' is in motion with respect to W, so an emf. is induced in it. This emf. is the same as obtained in (*a*), which agrees with experiment.

(*c*) Rotation of W, with everything else stationary, induces an emf. in the conductor AC' but it induces an equal and opposite emf. in the disk, so $V = 0$.

8. FLEXIBLE LOOP

Statement

A loop of flexible wire W_1 (Fig. 13*a*) carries a steady current I_1. Attached to W_1 is a second wire W_2 which is connected to an electrostatic voltmeter V. The composite loop is deformed in an arbitrary way. What is the induced emf.?

To make the problem more amenable to calculation, consider the special case of Fig. 13*b*. The loops have been greatly expanded in the y-direction so that we have two long parallel conductors W_1 of radius a whose axes are separated by distance ξ, ($\xi \gg a$). The conductor at

FIG. 13a. Double flexible loop. Is an emf. induced by deforming the loop?

FIG. 13b. Special case of Fig. 13a.

FIG. 13c. Analysis of Fig. 13b.

$x = 0$ is fixed, while the conductor at $x = \xi$ is moving in the x-direction at constant velocity $\mathbf{v}$. Cemented to the inside of each W_1 is an enameled wire W_2 of small diameter, which is connected to the voltmeter.

A Classical Solution

Since there are no moving contacts to cause possible ambiguity, we use Maxwell's equation,

$$\text{curl } \mathbf{E} = -\partial \mathbf{B}/\partial t$$

or

$$V = -\int \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathfrak{A}. \tag{20}$$

The flux density at an arbitrary point P is

$$B(x, \xi) = \frac{I}{2\pi\epsilon c^2} \frac{\xi}{x(\xi - x)},$$

or

$$\frac{\partial B}{\partial t} = \frac{\partial B}{\partial \xi} \frac{d\xi}{dt} = -\frac{Iv}{2\pi\epsilon c^2} \frac{1}{(\xi - x)^2}.$$

Therefore, according to Eq. 20, the induced emf. per unit length in the y-direction is

$$V = -\int_a^{\xi - a} \frac{\partial B}{\partial t}\, dx = \frac{Iv}{2\pi\epsilon c^2 a} \left(\frac{\xi - 2a}{\xi - a} \right). \tag{21}$$

In the usual case of $a \ll \xi$, the bracket becomes essentially unity and the induced emf. per unit length approaches infinity as $a \to 0$!

Electrodynamic Solution

Consider the left current-carrying conductor and a point P in the right voltmeter wire (Fig. 13c). Here $\theta_w = \pi/2 + \theta_1$, $\cos\theta_w = -\sin\theta_1$, $\sin\theta_w = \cos\theta_1$, and Eq. 2 becomes

$$d\mathfrak{F}_2 = \mathbf{a}_r \frac{3|I_1|v_w ds_1}{4\pi\epsilon c^2 r^2} \cos\theta_1 \sin\theta_1.$$

The total force per unit charge, caused by the left conductor, is

$$\mathfrak{F} = \mathbf{a}_y \frac{3|I_1|v_w(\xi - a)}{2\pi\epsilon c^2} \int_0^\infty \frac{y^2 dy}{r^5} = \frac{|I_1|v_w}{2\pi\epsilon c^2(\xi - a)}.$$

Thus the induced emf. in the two wires W_3, per unit y-length, is

$$V = \frac{|I_1| v_w}{\pi \epsilon c^2 (\xi - a)}, \tag{22}$$

which does not agree with Eq. 21 but yields a reasonable voltage for any value of a.

9. BLONDEL EXPERIMENT (5)

Statement

Two V-pulleys D and D' of insulating material are arranged on parallel shafts at some distance from each other, Fig. 14. One end of a

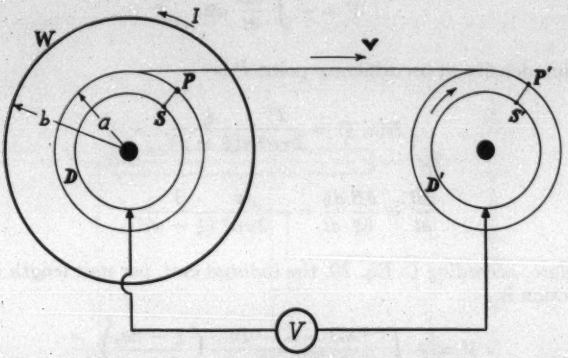

FIG. 14. The Blondel experiment. Conductor is unwrapped from pulley D, thus changing the flux linkages. Is an emf. induced in the circuit?

long flexible wire is soldered to P and is wound in the groove of the pulley. The other end of the wire is soldered to P'. Points P and P' are connected to slip rings S and S', which actually have the same diameter as the pulleys. A magnetic field is produced in D by direct current I in a circular loop W which is in the plane of D.

When D' is turned in the direction of the arrow, thereby unwinding the coil on D, what emf. is indicated by V?

A Classical Solution

The pulley D' is so far from W that the increase in its number of turns produces no emf. The wire that is unwound from D is moving longitudinally through a magnetic field, so no emf. is produced in it. The lower part of the circuit (including V) is stationary and produces no emf. We can therefore concentrate on the coil wound on D.

A fundamental principle of circuit theory (6) is that

$$V = -\frac{d\Lambda}{dt},$$

where $\Lambda = N\Phi$ = flux linkages. In this case, Φ is constant, so the induced emf. is

$$V = -\Phi\frac{dN}{dt} = \frac{\Phi v}{2\pi a}. \tag{23}$$

But experiment shows that *the emf. is zero.*

Electrodynamic Solution

Equation 18 expresses the force per unit charge at any point within the loop W, caused by rotation about the axis. There are only two possible seats of induced emf.:

(a) In the circular loops of wire on D,
(b) In the straight wire joining the two pulleys.

According to Section 7, the force on an electron is radial if the motion is a rotation. Thus no emf. is induced in the circular loops. Similarly, one can prove by use of Eq. 2 that the force on electrons in the straight wire is perpendicular to the direction of motion. Thus neither (a) nor (b) contributes anything and the voltmeter reads zero.

10. CULLWICK EXPERIMENT (7)

Statement

A long, straight wire C carries a direct current I_1 (Fig. 15). Coaxial with the wire is a steel cylindrical ring R with radii a and b and permeability μ. Sliding contacts A and B are connected to a stationary voltmeter V. When the ring moves upward at uniform velocity $\mathbf{v}$, an emf. is induced in the circuit. Will this emf. be different if the steel ring is replaced by a brass ring of the same size?

A Classical Solution

At any radius r, the magnetic field strength is

$$H = \frac{I_1}{2\pi r},$$

and $B_0 = \mu_0 H$ in air, $B = \mu H$ in the steel. When the ring moves upward by distance Δz, the flux linked by the circuit is increased by

$$\Delta\Phi = \Delta z\left[\int_a^b B dr - \int_a^b B_0 dr\right] = \Delta z\frac{(\mu - \mu_0)I_1}{2\pi}\ln(b/a).$$

In accordance with Maxwell's equations, the induced emf. is

$$V = -\frac{d\Phi}{dt} = -\frac{d\Phi}{dz}\frac{dz}{dt}$$

or

$$V = -\frac{I_1 v}{2\pi}(\mu - \mu_0)\ln b/a. \tag{24}$$

According to Maxwell's equations, therefore, the brass ring ($\mu = \mu_0$) gives zero emf. while the steel ring gives an emf. that depends on permeability. Experiment shows (7), however, that *an emf. is induced in both cases and this emf. is independent of permeability.*

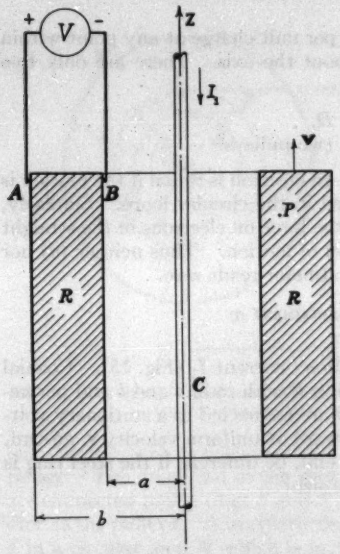

FIG. 15. The Cullwick experiment. Steel tube R moves upward, thus changing flux linkages in voltmeter circuit.

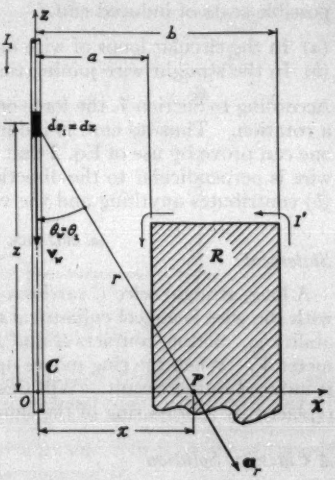

FIG. 16. Analysis of Fig. 15.

Electrodynamic Solution

Consider an arbitrary point P within the material of R and moving with it. The relative velocity $\mathbf{v}_w$ of the wire with respect to R is in the negative z-direction (Fig. 16). From Eq. 2,

$$d\mathfrak{F}_2 = \mathbf{a}_r \frac{|I_1|v_w ds_1}{4\pi\epsilon c^2 r^2}(2\sin^2\theta_1 - \cos^2\theta_1),$$

and the total effect of the vertical wire is

$$\mathfrak{F} = \mathbf{a}_z \frac{|I_1|v_w}{2\pi\epsilon c^2} \int_0^\infty (2\sin^2\theta_1 - \cos^2\theta_1 \sin\theta_1) \frac{dz}{r^2}$$

$$= \mathbf{a}_z \frac{|I_1|v_w}{2\pi\epsilon c^2 x}.$$

Thus the voltage appearing everywhere in the ring between inside and outside surfaces is

$$V = \frac{|I_1|v_w}{2\pi\epsilon c^2} \int_a^b \frac{dx}{x} = \frac{|I_1|v_w}{2\pi\epsilon c^2} \ln (b/a). \tag{25}$$

There are no eddy currents. The field strength $\mathfrak{F}$ is independent of the angle about the axis and independent of z.

With a steel tube, we must also include the effect of induced magnetism. Because of domain orientation in the material, there will be Amperian currents in the xz-plane. The total effect of these currents is represented by a fictitious current sheet I' which is directed upward over the entire outer surface of the ring and downward over the inner surface. The effect of this current is determined by use of Eq. 2. But since P is stationary with respect to the ring, $\mathbf{v}_w = 0$ and the Amperian currents contribute nothing to the force on an electron at P. Thus Eq. 25 expresses the entire induced emf. and shows that this emf. is *independent of the material of the ring*. The polarity is as shown in Fig. 15.

11. LOOP OF ZERO RESISTANCE

Statement

A large number of metallic elements and alloys become superconducting when the temperature is reduced below a critical value. Critical temperatures for a few elements are lead 7.22° K, mercury 4.15°, tin 3.73°, aluminum 1.20°.

A loop L_2 (Fig. 17) is cooled below the critical temperature and thus has zero resistance. The loop L_1 is at room temperature and is excited with alternating current,

$$I(t) = \sqrt{2}\, I_1^* e^{i\omega t}.$$

What is the current in L_2?

Classical Treatment

We apply two of Maxwell's equations:

$$\text{curl } \mathbf{E}^* = -i\omega\mathbf{B}^*, \tag{26}$$

$$\mathbf{E}^* = \mathbf{J}^* \mathfrak{R}, \tag{27}$$

where $\mathbf{J}^*$ is rms. current density and $\mathfrak{R}$ is resistivity. Surely these equations are applicable, since there are no moving contacts and there is no motion between L_1 and L_2. We employ also the universally accepted definition

$$V^* = \oint \mathbf{E}^* \cdot d\mathbf{s}. \tag{28}$$

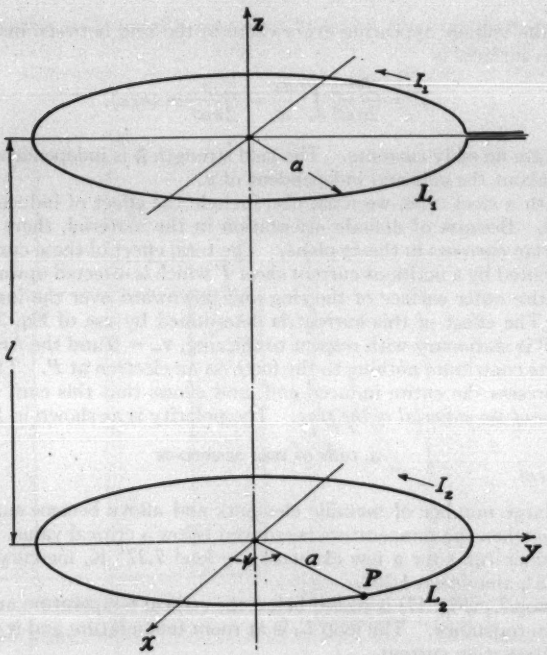

FIG. 17. To find I_2 in a zero-resistance loop L_2, caused by a given alternating current I_1 in L_1.

From Eqs. 26 and 28,

$$V^* = -i\omega\Phi^*, \tag{29}$$

where Φ^* is the total rms. flux linking L_2. From Eqs. 27 and 28,

$$V^* = a\int_0^{2\pi} E^* d\psi = 2\pi a J^* \mathfrak{R}. \tag{30}$$

But $\mathfrak{R} = 0$, so $V^* = 0$ in Eqs. 29 and 30. Therefore $\Phi^* = 0$ and no flux can link loop L_2.

Does this not mean that $I_2^* = 0$? The answer is obvious from circuit theory but is not quite so easy to grasp on a field-theory basis.

Electrodynamic Solution

A current element $I_1 ds_1$ in the upper conductor of Fig. 17 produces a force on electrons in L_2. This force is obtained from the acceleration term of Eq. 1*a*. Integration around L_1 gives the total force per unit charge at P. According to a previous paper (1, p. 374)

$$\mathfrak{F} = \mathbf{F}/Q_2 = -\mathbf{a}_\psi \omega I_1^* \frac{(4a^2+l^2)^{\frac{1}{2}}}{4\pi\epsilon c^2}\left[\left(\frac{4a^2+2l^2}{4a^2+l^2}\right)K(k) - 2E(k)\right], \quad (31)$$

where K and E are complete elliptic integrals with modulus

$$k = 2a/(4a^2 + l^2)^{\frac{1}{2}}.$$

The current in loop L_2 also produces an acceleration force on electrons at P:

$$\mathfrak{F} = -\mathbf{a}_\psi \omega I_2^* \frac{a}{2\pi\epsilon c^2}[K(1) - 2E(1)]. \quad (32)$$

Additional forces, such as those caused by the fact that electrons are moving in circular paths rather than straight lines, are negligible as in Section 7. So the only appreciable forces are those given by Eqs. 31 and 32.

Since the resistivity of L_2 is zero, the total $\mathfrak{F}$ must be zero. Equating the sum of Eqs. 31 and 32 to zero, we obtain a definite value of current in the second loop:

$$I_2^* = -I_1^* \frac{(4a^2 + l^2)^{\frac{1}{2}}}{2a}\left[\frac{\left(\frac{4a^2 + 2l^2}{4a^2 + l^2}\right)K(k) - 2E(k)}{K(1) - 2E(1)}\right]. \quad (33)$$

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New Aircraft Servo Motor.—A new miniature d.c. servo-motor, capable of withstanding a high potential of 1500 volts and of responding to field currents of 0.0075 amp., has been announced by the General Electric Company's Specialty Component Motor Department. Suited for aircraft applications on blowers, actuators, tuners and similar devices, the new motor will operate equally well at sea level or at 50,000-ft. altitude and within temperature limits of −65°F. to 165°F. It is also used as a prime mover in gun direction computer systems, electronic devices, and can be modified for other aircraft and missile applications.

Weighing less than eight ounces, the motor may be wound as a straight shunt machine when required. It is reversed by a small double-pole, double-throw relay and is operated by separate excitation of the armature and differentially wound-shunt fields, with the signal differential between the field structures utilized as its control.

The new G-E d.c. servo motor, designated 5BBY13DJ7, draws maximum armature current of 0.8 amps. from a 28 volt line. It is rated at 0.002 hp. at 6500 rmp., and can be geared to speeds as low as 130 rpm.

Telephone Fire and Police Alarms.—"Fire!" or "Police!"—the cry for help can now be telephoned directly by the public from street corners. A new telephone system, developed at Bell Telephone Laboratories, may eventually become as commonplace as the familiar red fire alarm boxes in which a handle is pulled to send out a telegraphic signal. A number of cities, including Omaha, Neb., Indianapolis, Ind., Miami, Fla., Syracuse, N. Y. and Sioux Falls, S. D., have approved the use of the system. Omaha already has it in operation.

The new system enables firemen or policemen to talk directly with the person placing the alarm. They can immediately determine the exact location of the emergency, its extent and the best type of equipment to dispatch.

Outdoor telephone sets encased in brightly painted cast aluminum housings are mounted at street corners. The spring door can be quickly flung back and the receiver snatched from its hook to summon aid in any emergency.

In a typical installation, when a call is made, a light flashes on a console at alarm headquarters until the call is answered. The light shows the box number and its location. There are no switches or dials; the caller is in direct contact. The console light remains on after the dispatcher answers until released by the operator so he knows where the alarm is coming from even if the person reporting the emergency is too excited to talk.

If the call is for police, the fire department operator immediately transfers the call to the police department switchboard. Calls may be relayed from one switchboard to another.

An automatic voice recorder flips on when the call comes in to take the caller's report. Another recorder can be provided which marks the time and box location.

An optional feature of the system which may be provided is a special bypass switch which enables foot patrolmen to report directly to police headquarters without having calls go through the fire department.

All reporting lines are under continuous electrical test which signals the operator at the console and the telephone company in the event of damage to the circuits.

TRIAXIAL PLASTIC STRESS-STRAIN RELATIONS FOR AN ALUMINUM ALLOY 14S-T4

BY

JOSEPH MARIN [1] AND H. A. B. WISEMAN [1]

SUMMARY

This paper gives the results of an investigation on the plastic stress-strain relations of an aluminum alloy 14S-T4 subjected to triaxial stresses. In addition to providing information on the triaxial plastic stress-strain relations, this study serves to provide a further check on the validity of the theories of plasticity used to predict plastic stress-strain relations for combined stresses. The triaxial stresses considered consisted of two equal compressive principal stresses and a third tensile principal stress. The stresses were produced by subjecting a solid cylindrical specimen to radial hydraulic pressure in addition to axial tension. Two types of triaxial stress tests were made. In one type of test the loads were applied so that the ratio of the principal stresses remained essentially constant during the test. For these constant stress-ratio tests, the influence of the stress ratio on the plastic stress-strain relations was investigated. In a second type of test the ratio of the principal stresses was varied during the test. The variable stress-ratio type test was conducted in order to provide a further check on the validity of the simple flow theory.

The constant stress ratio tests for various principal stress ratio showed good agreement between the test results and the predictions of the simple flow theory of plasticity. However, the variable stress-ratio test results did not agree with the predictions of the theory.

INTRODUCTION

In recent years a number of investigations have been conducted where the plastic stress-strain relations in metals have been obtained for two dimensional or biaxial states of stress. In most cases, these investigations have been conducted to determine the validity of the theories of plasticity used for predicting plastic stress-strain relations under combined stresses. The foregoing studies have usually been made using thin walled tubes of circular cross-section. Biaxial stresses are produced in these tubes by applying either axial tension and internal pressure or axial tension and torsion. Very little information is available, however, on the influence of triaxial stresses on the plastic stress-strain relations. Most of the available information is of a qualitative

[1] Department of Engineering Mechanics, The Pennsylvania State University, University Park, Pa.

nature. A summary of previous triaxial stress investigations is given in reference (1).[2]

It is of importance to obtain more information on the triaxial plastic stress-strain relations of materials, since little information is available for this basic type of stress. Furthermore, triaxial states of stress occur in various machine and structural components and for this reason it is desirable to know the plastic stress-strain relations for triaxial stresses. From a fundamental point of view, it is important to have information on plastic triaxial stress-strain relations because these stresses represent the general state of stress that must be considered in the formulation of a plasticity theory.

TRIAXIAL STRESS INVESTIGATION OF AN ALUMINUM ALLOY 14S-T4

Material Tested and Specimens

The material tested in this investigation was an aluminum alloy designated as 14S-T4. The material was supplied by the Aluminum Company of America in form of extruded solid rod, 1 in. in diameter and 10 ft. long. The normal composition of this material, in addition to aluminum and normal impurities, consists of 4.4 per cent copper, 0.8 per cent silicon, 0.8 per cent manganese, and 0.4 per cent magnesium.

The dimensions of the machined specimens are given in Fig. 1. The

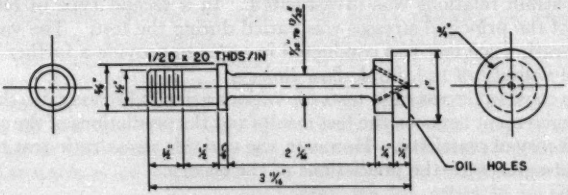

FIG. 1. Triaxial stress specimen.

test section of the specimen was approximately 2 in. in length and had a diameter which varied from about 7/32 to 7/16 of an inch. By varying the diameter of the test specimen, different constant principal stress ratios could be obtained.

Testing Machine

Only a brief description of the testing machine will be given here since reference (1) describes the machine in detail. A schematic drawing of the triaxial testing machine is shown in Fig. 2. Hydraulic fluid acts on the large piston of the ram No. 12 which acts through the piston seat

[2] The boldface numbers in parentheses refer to the references appended to this paper.

No. 10 on the small piston No. 8. The ratio of the area of the large piston (No. 12) to that of the small piston (No. 8) is an approximate measure of the increase in pressure attainable.

The hydraulic fluid under pressure is transmitted through the thick walled tube No. 4, the six way connector No. 5 and another thick walled tube No. 6 into the testing vessel No. 2. The test specimen No. 3 is placed in the testing vessel and subjected to hydraulic pressure. This pressure produces radial compressive and axial tensile stresses in the

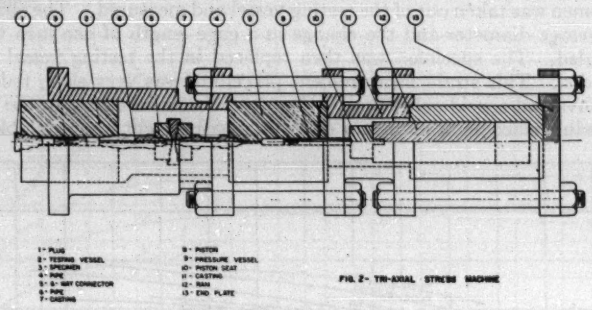

FIG. 2. Triaxial stress machine.

specimen. For tests in which it is necessary to vary the axial stress independent of the pressure, the plug No. 1 is removed from the testing vessel and another hydraulic pressure intensifier is connected, in the same manner as the one shown in Fig. 2. The hydraulic fluid from the second pressure intensifier produces an axial compressive load on the ends of the specimen, counteracting the axial tensile load due to the pressure from the first intensifier. By varying the pressure from the second intensifier, the net axial stress can be controlled.

Measurement of Pressure

The maximum pressure used in this series of tests did not exceed 100,000 psi. A Bourdon type of pressure gage of 100,000-psi. capacity was used to measure the hydraulic pressure developed by one of the pressure intensifiers. This gage was connected into the six way connector (No. 5) by means of special fittings.

Only one Bourdon type pressure gage of 100,000-psi. capacity was available for this series of tests. To measure the pressure produced by the second pressure intensifier another type of gage was used. This gage consisted of a specially wound coil of manganin wire which is immersed in the fluid of the high pressure system. It has been found that the electrical resistance of manganin wire varies linearly with pressure. This coil was calibrated with a free floating piston dead weight tester of

50,000 psi. and the resulting linear pressure electrical resistance curve was linearly extrapolated to 100,000 psi. Bridgman (2) has found that this linear relationship is valid to at least 185,000 psi.

Measurement of Strains

No attempt was made to measure the elastic strains produced in the specimens. To measure the plastic strains the specimens were loaded until plastic flow had occurred. The loads were then removed and the specimen was taken out of the testing vessel and measured. The change in average diameter and the change in average gage length of one inch were recorded. The specimen was then replaced in the testing vessel and reloaded. This strain measurement procedure was very slow, tedious and involved considerable time. However, it was necessary to use this procedure since no other means of strain measurement was available.

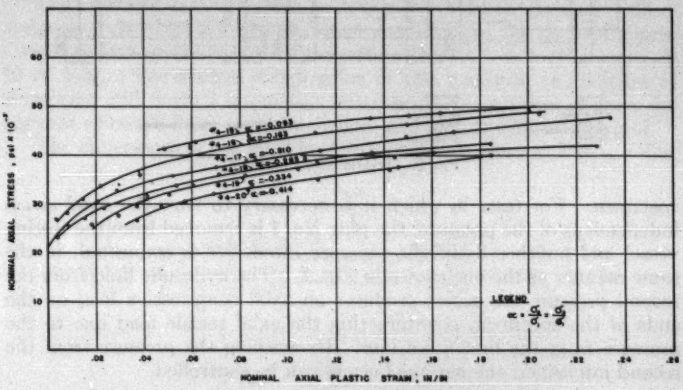

FIG. 3. Nominal stress-strain relations for constant stress-ratio tests.

CONSTANT STRESS-RATIO TESTS

Plastic stress-strain relations for various constant values of the triaxial stress ratios were obtained using the triaxial machine herein described. These data provided information on the influence of triaxial stresses on the plastic stress-strain relations. The tests were also conducted to check further on the validity of the simple flow theory in predicting plastic stress-strain relations under combined stresses.

Conventional Stress-Strain Relations

The average conventional stress-strain curves for the various principal stress ratios and for the axial and radial stress components are shown in Figs. 3 and 4. The values of the nominal radial stresses are equal to

the applied pressure while the value of the nominal axial stress can be shown to be (1)

$$\sigma_1' = \left(\frac{d_1^2 - d_2^2}{d_2^2}\right) p_1 \tag{1}$$

where d_1 is the diameter of the movable head of the specimen, d_2 is the diameter of the test section of the specimen and p_1 is the hydraulic pressure.

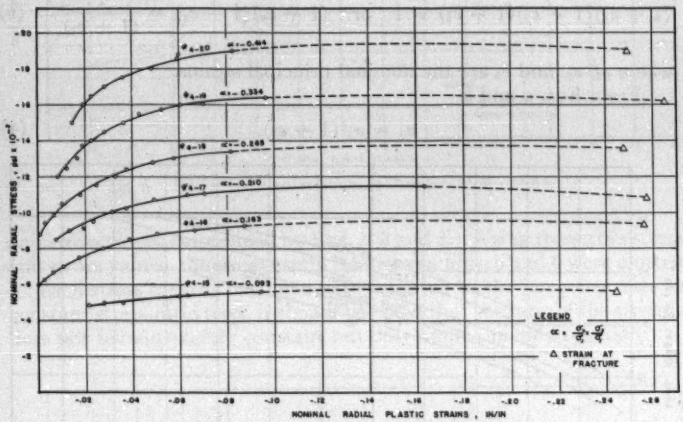

FIG. 4. Nominal stress-strain relations for constant stress-ratio tests.

The nominal axial strain is

$$e_1 = \frac{\Delta l_0}{l_0} \tag{2}$$

where Δl_0 is the plastic change in length, and l_0 is the original gage length.

The radial strains are equal to the tangential strains and have a value

$$e_2 = e_3 = -\frac{\Delta d_0}{d_0} \tag{3}$$

where Δd_0 is the plastic change in diameter and d_0 is the original diameter.

True Stress-Strain Relations

To determine the true plastic stress-strain relations, the change in the dimensions of the specimens must be considered and the actual stresses

and strains calculated. The value of the actual axial stress (σ_1) in terms of the nominal axial stress (σ_1^1) can be obtained by noting that the total stress is $\sigma_1 A$ or $\sigma_1^1 A_0$ where A and A_0 are, respectively, the actual and initial cross-sectional areas. That is

$$\sigma_1 A = \sigma_1^1 A_0 \quad \text{or} \quad \sigma_1(1 + e_2)(1 + e_3) = \sigma_1^1. \tag{a}$$

For constancy of volume

$$(1 + e_1)(1 + e_2)(1 + e_3) = 1 \quad \text{or} \quad (1 + e_2)(1 + e_3) = \frac{1}{(1 + e_1)} \tag{b}$$

where e_1, e_2, and e_3 are the nominal principal strains.

From Eqs. *a* and *b*

$$\sigma_1 = \sigma_1^1(1 + e_1). \tag{4}$$

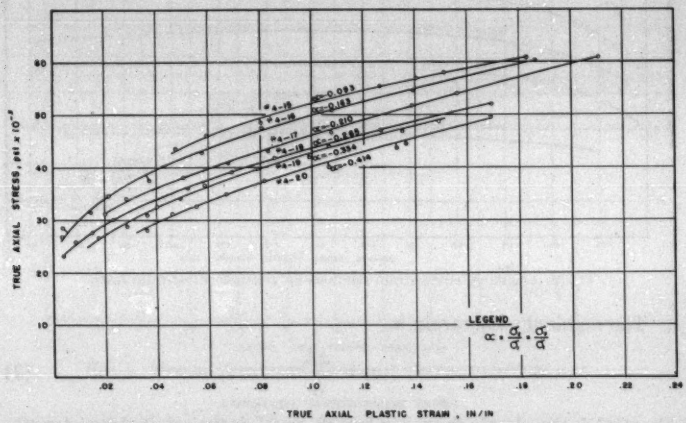

FIG. 5. True stress-strain relations for constant stress-ratio tests.

The true radial stresses will remain equal to the applied pressure. The true strains will also be different due to the change in dimensions. The true strains corresponding to nominal strains e_1, e_2, and e_3 have been shown to be (3)

$$\epsilon_1 = \log_e (1 + e_1) \tag{5}$$

and

$$\epsilon_2 = \epsilon_3 = \log_e (1 + e_2). \tag{6}$$

Based on Eqs. 4, 5 and 6 the true axial stress-strain and true radial stress-strain values were computed for each test using the nominal strain

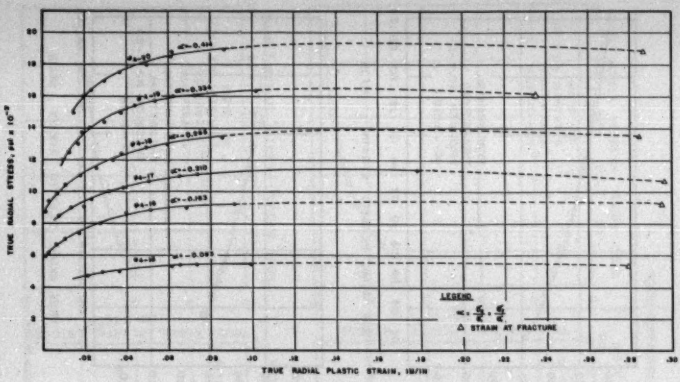

Fig. 6. True stress-strain relations for constant stress-ratio tests.

and stress values determined by Eqs. 1, 2 and 3. Using these true stress and strain values, the stress-strain relations in Figs. 5 and 6 were plotted for each stress ratio as indicated. In referring to the foregoing tests as constant stress-ratio tests, it should be noted that the ratio of the stresses does not remain exactly constant but only approximately constant.

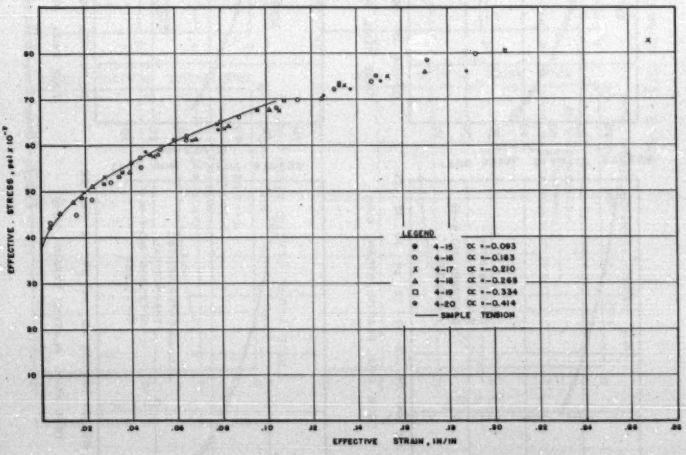

FIG. 7. Effective stress-strain relations for constant stress-ratio tests.

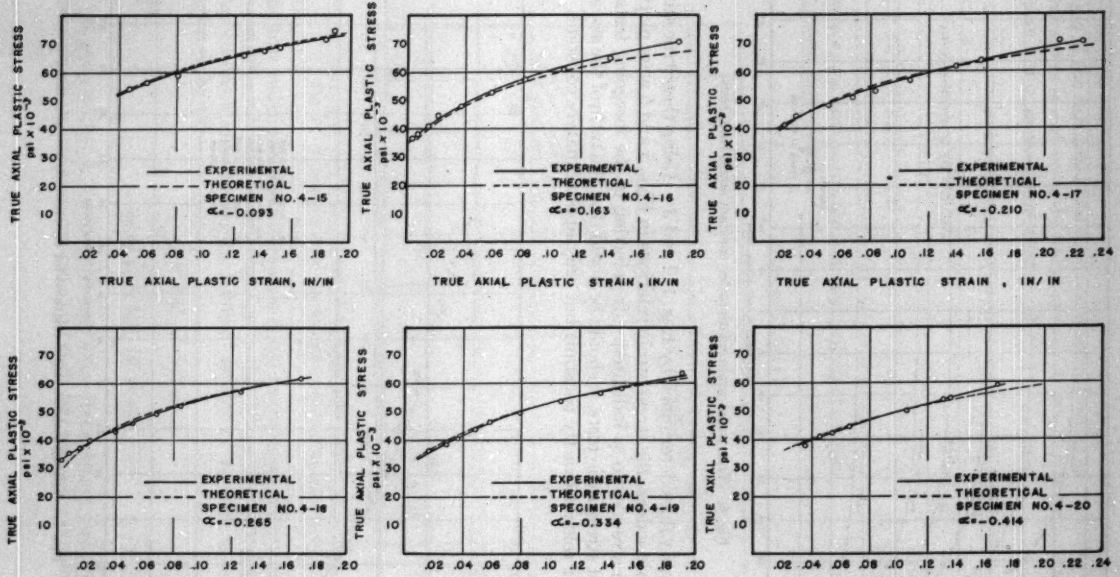

FIG. 8. True stress-strain relations for constant stress-ratio tests.

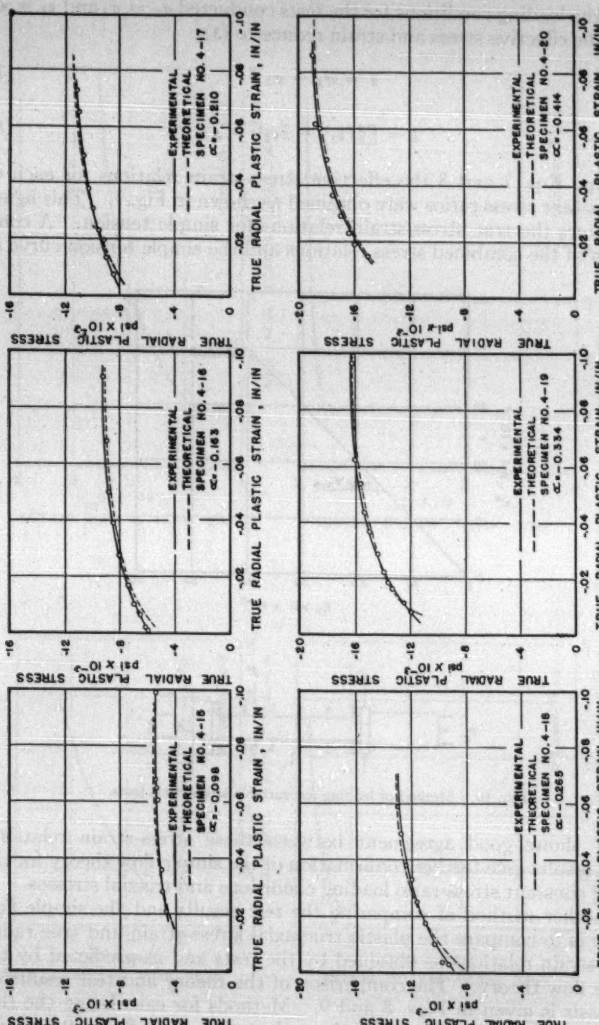

FIG. 9. True stress-strain relations for constant stress-ratio tests.

In the loading conditions for the tests conducted $\sigma_2 = \sigma_3$ and $\epsilon_2 = \epsilon_3$. Then the effective stress and strain reduce to (3)

$$\bar{\sigma} = \sigma_1 - \sigma_2 \tag{7}$$

and

$$\bar{\epsilon} = [\tfrac{2}{3}(\epsilon_1^2 + 2\epsilon_2^2)]^{\frac{1}{2}}. \tag{8}$$

Using Eqs. 7 and 8 the effective stress-strain relations for each of the constant stress ratios were obtained as shown in Fig. 7. This figure also shows the true stress-strain relations for simple tension. A comparison of the combined stress relations and the simple tension curve in

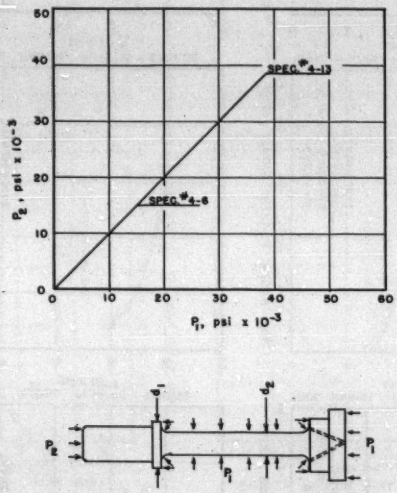

FIG. 10. Method of loading for variable stress-ratio tests.

Fig. 7 shows good agreement between these stress-strain relations. These results give further confirmation of the simple flow theory for the case of constant stress-ratio loading conditions and triaxial stresses.

Another method of comparing the test results and the simple flow theory is to compare the plastic true axial stress-strain and true radial stress-strain relations as obtained by the tests and as predicted by the simple flow theory. The comparison of the theory and test results on this basis is given in Figs. 8 and 9. Methods for calculating the theoretical plastic stress-strain relations plotted in Figs. 8 and 9 are outlined in reference (3).

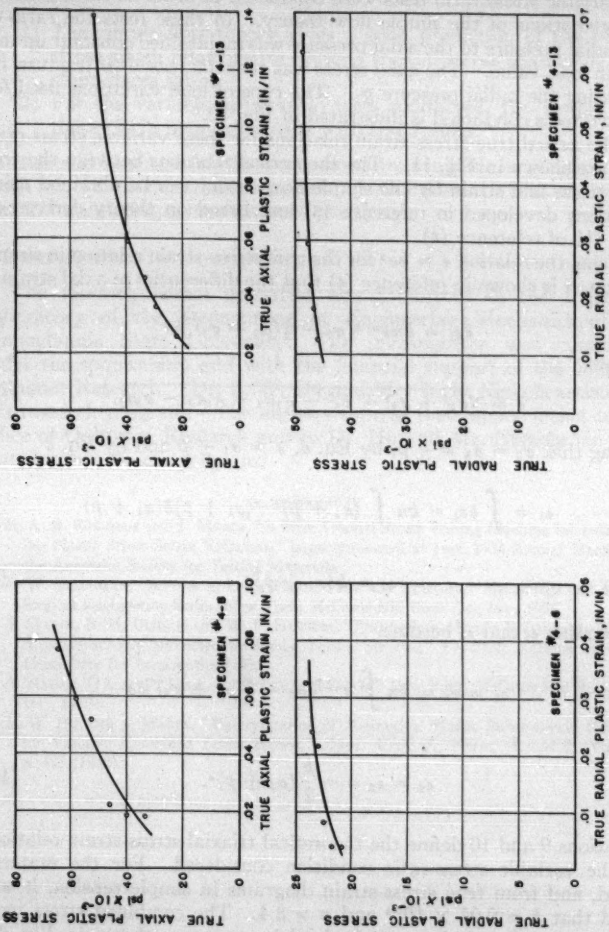

FIG. 11. Experimental true stress-strain relations for variable stress-ratio tests.

VARIABLE STRESS-RATIO TESTS

Variable stress-ratio tests were conducted in order to further check the predictions of the simple flow theory. In these tests the ratio of the radial pressure to the axial pressure was maintained constant up to a certain load value. The axial stress was then increased to fracture by increasing the radial pressure p_1. The type of load variations used for the two tests conducted is illustrated in Fig. 10.

The actual true-stress-strain relations for these variable stress-ratio tests are shown in Fig. 11. The theoretical relations between the true axial stress and strain by the simple flow theory can be obtained using equations developed in reference (5) and based on theory derived on page 411 of reference (4).

Using the relation $\epsilon = k\sigma^n$ for the true stress-strain relation in simple tension, it is shown in reference (4) that the differential of axial strain is

$$\delta\epsilon_1 = kn\bar{\sigma}^{n-2}\left[\sigma_1 - \tfrac{1}{2}(\sigma_2 + \sigma_3)\right]\delta\bar{\sigma} \qquad (c)$$

where

$$\bar{\sigma} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_3\sigma_1}. \qquad (d)$$

Noting that $\sigma_2 = \sigma_3 = -p$, by Eq. d, $\bar{\sigma} = \sigma_1 + p$ and by Eq. c

$$\epsilon_1 = \int \delta\epsilon_1 = kn \int (\sigma_1 + p)^{n-2}(\sigma_1 + p)\delta(\sigma_1 + p)$$

or

$$\epsilon_1 = k(\sigma_1 + p)^n. \qquad (9)$$

The strains ϵ_2 and ϵ_3 become

$$\epsilon_2 = \epsilon_3 = kn \int \bar{\sigma}^{n-2}\left[\sigma_2 - \tfrac{1}{2}(\sigma_1 + \sigma_3)\right]\delta\bar{\sigma}$$

or

$$\epsilon_2 = \epsilon_3 = -\frac{k}{2}(\sigma_1 + p)^n. \qquad (10)$$

Equations 9 and 10 define the theoretical triaxial stress-strain relations for the variable stress-ratio condition considered. For the material tested, and from true stress-strain diagrams in simple tension, it was found that $k = 9.97 \times 10^{-6}$ and $n = 8.4$. The combined stress variable stress-ratio relations as obtained by tests are shown in Fig. 11. The theoretical relations based on Eqs. 9 and 10 were found to be in very poor agreement with the test results in Fig. 11 and for this reason they are not plotted in Fig. 11.

CONCLUSIONS

For the aluminum alloy 14S-T4 tested the following conclusions can be made:

(1) The simple flow theory gives a good prediction of the plastic stress-strain relations for various triaxial stress tests using constant stress ratios.
(2) For the variable stress-ratio tests conducted, the simple flow theory is in poor agreement with test results.

It should be noted that few test results are available on plastic stress-strain relations under triaxial stresses. Such information is very important in formulating a mechanics of plasticity.

Acknowledgments

The research herein described was conducted in the Plasticity Laboratory of the Department of Engineering Mechanics of the Pennsylvania State University. The investigation was conducted under the sponsorship and with the financial support of the Office of Ordnance Research. Dr. L. W. Hu and Mr. W. E. Nickola assisted in this research program. The authors express their appreciation to the Office of Ordnance Research and to Dr. Hu and Mr. Nickola for their contributions to this program.

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Electronic Tubes for Locomotives.—Electric locomotives with electronic tubes will soon be replacing the original split-phase electrics on the tracks of The Virginian Railway Company. Together with the four 6800-hp. motor-generator locomotives built by G.E. in 1948, they will handle all traffic on the electrified section.

Guy W. Wilson, General Manager of the General Electric Company's Locomotive and Car Equipment Department, has announced that G. E. would build twelve 3300 horsepower rectifier locomotives for the Virginian for use between Roanoke, Va., and Mullens, W. Va., a distance of 134 miles over mountainous territory.

Power for the new locomotives will be taken from an overhead wire, reduced in voltage by a transformer, and fed into 12 rectifier tubes which convert the alternating current to direct current for the traction motors. These tubes are similar in function to rectifier tubes used in ordinary radio and TV sets for converting a.c. to d.c.

Mr. Wilson said this order is especially significant coming during the sixtieth anniversary of main line railroad electrification in the United States. "We feel that it marks a new mile-post in renewed interest in railroad electrification," he said.

The ability of rectifier locomotives to use commercial frequency power could open up many new possible railway applications, according to Mr. Wilson. In the case of locomotives, it is possible to use highly-developed, mass-produced diesel-electric locomotive components. This reduces the first cost of motive power which has been an obstacle to further electrification.

Functional in design, the new locomotives will be similar in engineering detail to the ten General Electric units recently shipped to the New York, New Haven, and Hartford Railroad for high-speed passenger service between New York and New Haven. These are believed to be the first such passenger locomotives of this type used in the United States.

In general appearance, the Virginian locomotives will resemble the "hood-type," diesel-electric road switcher. The engineman's cab will be located near the front end. Each locomotive will rate 3300 horsepower, and units can be operated in multiple to furnish greater power as required.

All of the locomotive's 197 tons will be carried on two 3-axle trucks. Each axle is powered with a d.c. traction motor of the GE-752 type which is widely used in diesel-electric locomotive service. There are no extra wheels to spread the weight.

Dynamic (electric) braking will be provided to hold trains on descending grades. This is considered a special advantage where heavy loads are handled in mountainous country, according to G-E engineers.

Each locomotive will have a pantograph trolley used to collect the 11,000 volts, 25-cycle, single-phase a.c. The current flows from the trolley to the main transformer and then to the 12 main rectifier tubes. Power output from the rectifiers supplies the six traction motors.

In recent years, the direct-current traction motor has benefited from the development of the diesel-electric locomotive. Mass production plus experience gained from thousands of motors in service have greatly reduced the manufacturing cost and maintenance expense.

Inside the operating cab the engineman's and fireman's platforms are raised. Controls, brake valves, and other instruments are placed for convenient and easy operation by the crew.

NUCLEAR ENERGY NEWS

DISTRIBUTION OF CYCLOTRON-PRODUCED RADIOISOTOPES

The Atomic Energy Commission has decided to discontinue, effective November 30, 1955, its program for the processing and distribution of cyclotron-produced radioisotopes because private industry appears to be prepared to assume this function.

The decision will not affect the Commission's program for the production and distribution of reactor-produced radioisotopes and electromagnetically-concentrated stable isotopes. The bulk of the radioisotopes distributed by the Commission has been produced in reactors. The Commission will also continue to perform, upon payment of applicable charges, service irradiations in its cyclotrons.

The AEC began the production, processing and distribution of cyclotron-produced radioisotopes in 1949. The purpose of the program was to assist medical and biological research by providing radioisotopes that could not be produced in a nuclear reactor or could not be prepared from reactor-produced radioisotopes to meet activity specifications. The more important of these radioisotopes are Beryllium 7, Sodium 22, Arsenic 73 and 74, Iron 59, Zinc 65 and Iodine 125. A total of 793 shipments of cyclotron-produced radioisotopes with a total activity of 4,065 millicuries, was distributed from June 1949 through June 1955.

RADIATION SAFETY IN INDUSTRIAL OPERATIONS

The steps taken to protect workers from radiation in the Hanford plutonium plant were described at the Geneva Atoms-for-Peace Conference by Herbert M. Parker, head of the radiological sciences department at the Hanford plant, which is operated by the General Electric Company for the Atomic Energy Commission. He said that a sensible approach to radiation hazards in atomic energy installations is "to accept it as a necessary evil of the business."

He described the Hanford plant as a "good cross section" of the radiation hazards that may be expected in peaceful applications of atomic energy. He said that Hanford includes a number of high-power nuclear reactors, chemical separation plants, plutonium purification facilities, associated control laboratories and major research and development laboratories.

In 10 years at Hanford, Parker reported, there has been no case of serious overexposure to radiation or contamination, even though

"the magnitude of the radiation hazard can be described as the equivalent of handling some millions or tens of millions times the available world's supply of radium."

He said the Hanford record indicates that radiation hazards in the atomic energy industry can be adequately controlled by methods that are economically reasonable. Hanford studies indicate that the cost of operating with high standards is little more than the necessary cost for marginal protection. He said that this condition fortunately removes the risk of jeopardizing the future of the atomic energy industry by "over-zealous competitive reduction" of hazard controls.

SMALL AEC TEST REACTOR

The Atomic Energy Commission has asked industrial firms interested in designing and fabricating a small nuclear reactor for testing reactor cores to submit proposals for construction.

The reactor, to be built at the National Reactor Testing Station in Idaho, will be a high pressure water-moderated and water-cooled type. Tests of reactor cores will be conducted in the reactor under severe operating conditions as part of the Commission's program for determining safe operating limits and developing reactor designs incorporating maximun safety characteristics.

This small reactor is expected to cost between $250,000 and $500,000. It will supplement the $15,000,000 engineering test reactor that is to be built at the same site. (See this JOURNAL, Vol. 260, p. 132.)

The small reactor is to be in operation in mid-1956 and the large ETR the next year.

GENERAL ELECTRIC RADIATION LABORATORY

A new radiation laboratory was opened by the General Electric Company in mid-August. A former factory building at the Schenectady plant was converted to this new use. It now houses a 15-million-volt betatron, a high-voltage heavy-particle accelerator and a 1000-curie cobalt-60 source. It also contains several laboratories for the handling, testing, and analysis of radioactive materials.

The new facility will serve operating components of the company as well as carry on an engineering program of its own. This program will concern primarily studies of activation analysis, tracers, accelerators, radiation effects on various materials, and instrumentation.

ADDITIONAL PROCUREMENT OF ZIRCONIUM AND HAFNIUM

The Atomic Energy Commission plans to procure additional quantities of high-purity zirconium and hafnium metals to meet the increasing requirements of its reactor development program and of currently scheduled Navy projects. The tentative goal is 2,000,000

pounds of zirconium over a five-year period or 1,200,000 pounds over a three-year period.

Proposals for delivery of the zirconium are to cover delivery of as much hafnium metal as can be produced from the zirconium to be processed. Hafnium is obtained as a by-product of the purification of zirconium. Any production process that meets the specifications for the end products will be considered. The deadline for starting deliveries is expected to be July 1957.

The AEC at present has a contract with the Carborundum Metals Company, Inc., of Akron, N. Y., for delivery of 200,000 pounds of zirconium and 4,000 pounds of hafnium per year. The new procurement will be in addition to these amounts. In addition to the metal to be purchased by the AEC, quantities of zirconium and of hafnium may be required for privately-financed nuclear power plants. The AEC does not intend to provide these metals for such projects.

GAMMA-RAY ABSORPTOMETER FOR CHEMICAL ANALYSIS

The concentration of dissolved matter in a solution can be determined by means of gamma rays emitted by radioactive wastes in a gamma-ray absorptometer developed at the Hanford plutonium plant, which the General Electric Company operates for the Atomic Energy Commission. The absorptometer is used there to analyze chemical process solutions automatically and continuously.

Samples of a chemical solution are pumped automatically every few minutes to a disk-shaped lucite chamber, which is irradiated with gamma rays from a radioactive isotope. The more gamma rays absorbed by the sample, the higher is the concentration of dissolved matter in the solution. This method of analysis replaces slower manual methods. The gamma ray absorptometer is stable, simple, small, and economical to operate. Therefore it is expected to be used widely in industry.

The gamma rays for the analyzer can come from thulium-170 or selenium-75, both immediately available as waste products from the plutonium processing plant. Another possible isotope is americium-241, an element formed by the gradual decay of plutonium-241, but its availability in quantity depends on the development of better means of large-scale chemical separation of the element from impurities.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS

DETERMINATION OF COLOR DIFFERENCES

Accurate matching of colors is becoming increasingly important to modern industry. Household appliances such as stoves, refrigerators, washing machines, and clothes dryers may be assembled from parts produced on different production lines and finished with different materials. A noticeable color difference between parts may be objectionable to the customer and may hurt the sale of the product. Likewise, for many other uses, such as advertising signs, trade marks, traffic lights, and railroad signals, color is rigidly specified and closely controlled.

For many years manufacturers and purchasers of colored materials have employed inspectors to determine whether or not two samples are sufficiently similar in color to be called a "match." Frequently inspectors cannot agree, and in recent decades instruments have been developed to measure color and color differences precisely. But the extent to which instrumental values of color differences agree with estimates of human observers is a question that has never been satisfactorily resolved.

To obtain data which may lead to a solution of this problem, the National Bureau of Standards, in cooperation with the Porcelain Enamel Institute, embarked some years ago on a long-range research program. Although much experimental work remains to be done, preliminary phases of the investigation have provided significant information on the evaluation of color differences. This initial stage of the program has been carried out by J. C. Richmond, H. J. Keegan, and H. K. Hammond of the NBS staff and R. S. Hunter, Director of Hunterlab, with the cooperation of a number of industrial laboratories.

For estimation of color differences, approximately 200 porcelain enamel specimens were prepared in 15 groups of 13 panels each. Each group contained one panel which represented the "standard" color. The other panels of the group represented departures of approximately one and two steps in each of the six directions: lighter, darker, stronger, weaker, and toward the two adjacent hues. Thirty-four observers from 10 cooperating laboratories were then asked to estimate visually the relative magnitude and most prominent directions of the color differences between each specimen and the corresponding standard for that group. Nineteen of the 34 observers were classed as experienced in color matching while 15 were without experience in color work.

The data from the two groups of observers were averaged separately

and compared. While individual estimates of the color difference between any one specimen and its standard varied widely, the mean values of color-difference estimates for inexperienced observers were not significantly different from those of experienced observers. The statistical scatter of the estimates by the two groups of observers was also about the same. In 9 of the 15 sets of specimens, the difference between the statistical scatters, expressed as the average of the geometric standard deviations, was less than 5 per cent. In the other six groups, the inexperienced observers had the highest scatter in three colors—brown, gray, and purple—and the experienced observers had the highest scatter in the three others—fawn, light blue, and black.

In general, there was good correlation between experienced and inexperienced observers as regards the size of the statistical scatter for the various colors. Both groups tended to have smaller scatter for the colors near middle gray in the three dimensional color diagram—such as buff, fawn, dark green, gray, light blue, and cream—and larger scatter for the more saturated colors—such as purple, black, orange, brown, red, and white. A possible explanation for these trends might be the background against which the specimens were placed for viewing. Although the color of the background was not specified, it is very likely that in every case it was closer to middle gray than to the saturated colors.

The normal human eye is very sensitive to color differences and can tell quite easily when two colors match. However, it is much more difficult for the eye to judge the magnitude of departure from a color match. Colorimeters, on the other hand, are readily provided with numerical color scales from which differences may be precisely obtained. However, it is difficult to provide colorimeters with response functions that duplicate exactly those of the eye. Also, the magnitude and direction of color differences computed from instrumental data are functions of the color difference equation used.

The present investigation seeks to determine the extent to which colorimeters now in use can evaluate color differences and color-difference components in a manner which correlates with human vision. As a first step, the visual estimates of color difference were plotted against the corresponding instrumental values. Separate graphs were plotted for the three components of color differences: hue, lightness, and saturation. For some colors, the correlation between visual estimates and instrumental measurements was quite good, for other colors there was no apparent correlation, and in a few cases there was a suggestion of negative correlation. The most likely explanation for the cases of poor correlation is simply that the observers were given too difficult a task. That is, the color differences were so small that the observers could not agree on the magnitudes or directions of the hue, saturation, or lightness components of the differences.

While the extent to which instrumental measurements of color difference correlate with visual estimates has not been completely determined, useful conclusions can be drawn from the results obtained thus far. In general, it appears that color-difference meters properly operated are likely to be more reliable than the estimates of a single observer or even a small group of observers. Correlation of instrumental measurements with visual estimates will probably be satisfactory in most cases but should be verified for each color where such correlation is important. However, when color differences are less than two NBS units, low correlation may be expected. The numerical size of an instrumentally measured color difference will depend on the instrument and the color-difference equation used.

The investigation of color difference measurement is continuing. Present plans call for measurement of the porcelain enamel specimens with other types of colorimeters. These data, together with those from other sources, should ultimately lead to the development of a simpler and generally more useful equation for computing color difference. The spectrophotometer will be used to compile spectrophotometric data for each specimen, and these data will also be used to compute the magnitude of color differences between specimens. Although the spectrophotometer is the fundamental color measuring instrument, until recently it had seldom been used to measure small color differences. Development of analog computers to automatically integrate spectrophotometric curves has now made this use feasible.

ANALYSIS OF JET-ENGINE ALLOYS

In recent years the development of complex high-temperature alloys for jet engines has revealed a lack of accurate methods for chemical analysis of such materials. To obtain the desired combination of high heat resistance and low thermal expansion, the composition of these alloys must be carefully controlled during manufacture. Rapid spectrographic procedures can supply this control provided materials that have been carefully analyzed by other means are available for comparison. However, the high-temperature alloys contain some of the less well-known elements—molybdenum, titanium, tungsten, and niobium—whose chemical properties make analytical separation difficult. In such mixtures, even the determination of nickel—ordinarily a simple matter—may become involved.

Seeking a new approach to this problem, the National Bureau of Standards has developed an accurate procedure[1] for analyzing cobalt-base jet-engine alloys through use of ion exchange, that is, the differential retention of metal ions on the surfaces of certain resins. The

[1] For further details, see "Determination of Nickel, Manganese, Cobalt, and Iron in High-Temperature Alloys, Using Anion-Exchange Separations," by JOHN L. HAGUE, EDWIN E. MACZKOWSKE, and HARRY A. BRIGHT, *J. Research, NBS*, Vol. 53, p. 353 (1954) RP2552.

procedure permits the quantitative determination of nickel, manganese, cobalt, and iron in the presence of niobium, molybdenum, tantalum, tungsten, silicon, and copper. Development was carried out by J. L. Hague, E. E. Maczkowske, and H. A. Bright of the Bureau's Analytical Chemistry Section.

The NBS procedure was designed particularly for the analysis of an S–816 type of alloy containing 40 per cent of cobalt, 20 per cent of nickel, 20 per cent of chromium, and 4 per cent each of niobium, tungsten, and molybdenum. The remainder of the alloy is largely iron, manganese, carbon, and silicon.

In the analysis the first step is to dissolve the alloy in aqua regia. The niobium, tantalum, tungsten, and silicon are then rendered insoluble by hydrochloric-acid dehydration. The solution is treated with hydrogen sulfide to precipitate molybdenum and copper, and filtered. Repeated evaporation of the filtrate with hydrochloric acid and hydrogen peroxide provides a chloride solution of the elements in the proper valence for the ion-exchange fractionation.

The solution of metal chlorides is transferred to an anion-exchange column; and the nickel and manganese, with chromium and some other elements, are collected in the first fraction by washing with 9 *N* hydrochloric-acid solution. Cobalt is collected in a second fraction by washing with 4 *N* hydrochloric acid, and iron in a third by washing with 1 *N* hydrochloric acid.

The first fraction is divided into two parts, which are used to determine manganese and nickel by the persulfate-arsenite titration and dimethylglyoxime gravimetric methods, respectively. Cobalt is determined in the second fraction by electrolysis from a weakly ammoniacal chloride solution containing hydroxylamine hydrochloride, and iron is determined in the third fraction by reduction with stannous chloride and titration with dichromate.

THE FRANKLIN INSTITUTE

MINUTES OF THE MEDAL DAY MEETING

Wednesday, October 19, 1955

The annual Medal Day Ceremonies were held on Wednesday, October 19, 1955. Approximately 375 persons attended the reception and dinner in Franklin Hall. The invocation was delivered by the Reverend Philemon F. Sturges, Rector, St. Martin-in-the-Fields, Philadelphia, Pennsylvania. The dinner was concluded with a toast to Benjamin Franklin proposed by S. Wyman Rolph, President.

Guests adjourned to the Lecture Hall, where the President called the meeting to order at 8:30 P.M. The Stated Monthly Meeting was held in conjunction with the Medal Day exercises. Minutes of the Stated Meeting in May were approved as printed in the June issue of the JOURNAL.

Ralph H. McClarren, Chairman of the Committee on Science and the Arts, introduced twenty-six former Medalists and representatives of ten former Company Medalists who were present.

Henry B. Allen, Executive Vice-President and Secretary, reported on "The Institute in 1955"—giving highlights of Institute activities during the preceding year.

Following Dr. Allen's report, presentation ceremonies were opened by a short message from the President. The sponsor of each Medalist read the citation accompanying the award and introduced the Medalist. At the conclusion of the awards, Claude E. Shannon, Ballantine Medalist, gave an interesting talk on "Game Playing Machines."

The meeting adjuorned at 10:30 P.M.

(The full proceedings of Medal Day will be published in the December issue of the JOURNAL.)

HENRY B. ALLEN,
Secretary

PROGRAM

Reception for Medalists ..... THE HOSTESS COMMITTEE
Invocation ..... THE REVEREND PHILEMON F. STURGES
Dinner ..... MEDALISTS, OFFICIALS AND GUESTS
Toast to Benjamin Franklin ..... S. WYMAN ROLPH, *President*

ADJOURNMENT TO LECTURE HALL

Greetings ..... THE PRESIDENT
Stated Meeting of the Institute ..... THE PRESIDENT PRESIDING
Introduction of Former Medalists .....
..... RALPH H. MCCLARREN, *Chairman, Committee on Science and The Arts*
The Institute in 1955 ..... HENRY B. ALLEN, *Executive Vice-President*
Presentation of Awards ..... THE PRESIDENT
"Game Playing Machines" ..... CLAUDE E. SHANNON

MEDALISTS

To be Awarded a Cresson Medal (1848)

F. PHILIP BOWDEN

Reader in Physical Chemistry
University of Cambridge
Cambridge, England

To be Awarded Longstreth Medals (1890)

ROBERT W. BERRIMAN

Emulsion Chemist
Kodak Limited
Wealdstone, Harrow, England

RICHARD Y. CASE

Assistant Manager & Chief Engineer
Power Transmission Division
United States Rubber Company
Philadelphia, Pennsylvania

CECIL WALLER

Chief Emulsion Chemist
Ilford Limited
Ilford, London, England

To be Awarded a Levy Medal (1923)

DAVID ALBERT HUFFMAN

Assistant Professor of Electrical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

To be Awarded a Henderson Medal (1924)

CARLETON K. STEINS

Mechanical Engineer
The Pennsylvania Railroad Company
Philadelphia, Pennsylvania

To be Awarded Wetherill Medals (1925)

RENE A. HIGONNET

Research Engineer
Graphic Arts Research Foundation, Inc.
Cambridge, Massachusetts

LOUIS M. MOYROUD

Research Engineer
Graphic Arts Research Foundation, Inc.
Cambridge, Massachusetts

JACQUES Y. P. SEJOURNET

Directeur Général
Comptoir Industriel d'Etirage &
Profilage de Métaux
Paris, France

To be Awarded a Brown Medal (1938)

CHARLES S. LEOPOLD

Consulting Engineer
Philadelphia, Pennsylvania

To be Awarded a Ballantine Medal (1946)

CLAUDE ELWOOD SHANNON

Research Mathematician
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

LIBRARY

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Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

399 items were added the past month.

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JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

WARDE, J. M.: Recent Developments in the Technology of Ceramic Materials for Nuclear Energy Service
BELSTERLING, CHARLES A.: Analysis of a Differential Magnetic Amplifier with Flux Reset Control
DANFORTH, W. E. AND J. H. BODINE: Polarization in Thorium Oxide Crystals
GOLDWATER, J. H.: Effects of Electrolysis in the Thorium Oxide Emitter
JONES, E. E.: The Magnetostatic Force on Two Circular Cylindrical Conductors Carrying Uniform Steady Currents
CUNNINGHAM, W. J.: Nonlinear Oscillators with Constant Time Delay
HERMANN, JACOB AND C. S. ADES: Experimental Verification of Circular Plate Bending Theory

NOTE: The January 1956 issue of the JOURNAL will be a special issue commemorating the 250th anniversary of the birth of Benjamin Franklin. Nineteen papers, especially prepared for the occasion by representatives of societies and organizations with a Franklin tradition, will cover a wide range of subjects, both scientific and non-technical. The complete table of contents will be listed in the December JOURNAL.

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TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

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THE EFFECT OF ETHIONINE ON TUMOR GROWTH, CONTENT AND COMPOSITION OF FAT OF LIVERS AND TUMOR CELLS, AND GLYCOGEN CONTENT OF LIVER

BY

J. O. ELY AND WILLIAM G. BATT

A desire to investigate the combined effects on tumor growth of a chemical analog antagonistic in protein metabolism, one which is antagonistic in carbohydrate metabolism and one which is antagonistic in nucleic acid metabolism, led to a test of ethionine for its effects on the growth of the Krebs ascites carcinoma in mice. Since ethionine is an analog of the essential amino acid, methionine, and interferes with transmethylation, the incorporation of amino acids into proteins, and the conversion of methionine to cystine, it must also have a great effect on protein metabolism. Uptake of radio-methionine has been shown to be inhibited *in vivo* by ethionine (1) and the pattern of free amino acids in the liver is altered (2, 3).

Considerable inhibition of tumor growth has been obtained by incorporation of ethionine in the diet. Also evidence of abnormal accumulation of fat and changes in its composition in both the livers and tumor cells has been observed.

Male and female Swiss mice were used in separate experiments.

Since the effects of ethionine are counteracted by methionine, it was necessary to have a diet low in methionine, which necessitated a low protein content. The diets chosen were:

No. 1, low protein. A semisynthetic diet composed of casein, 7 parts; salt mixture, 4 parts; sucrose, 68 parts; Vitab, 2 parts; Mazola oil, 10 parts; and inert filler, 9 parts.

No. 2, same as No. 1 to which was added 0.1 g. of DL-ethionine (California Foundation for Biochemical Research) per 100 g.

No. 3, high protein. Fox Food Blox, an Allied Mills product containing about 25 per cent protein. This diet was used in order to compare the effect on tumor growth of a low protein diet with that of a customarily higher protein diet.

The mice were fed the diets for approximately 24 hours before implantation of the tumor.

The ascitic fluid from mice bearing the Krebs ascites carcinoma was diluted with 0.9 per cent sodium chloride solution until 0.2 ml. contained 5×10^6 tumor cells. That number of tumor cells was injected intraperitoneally into each mouse.

The increase in number of tumor cells, as the measure of growth,

was determined by cell counts of suitable dilutions of the washings of the peritoneal cavities of the mice.

Fat and its fractions were determined on livers and tumor cells by an application of the method of Saxon (4). The cells of ascitic fluid were not used for fat estimations if the fluid was appreciably colored by blood. The value marked "Fatty acids" is a combination of the fatty acids which were present in the tissues and the fatty acid of soaps which may have been present since extraction of fat was made in the presence of HCL to convert the soaps to fatty acids.

Total phosphorus content of the fat was determined by the method of Fiske and Subbarow (5). The factor 25.6 was used to convert the phosphorus value of the fat into phospholipin value on the assumption that lecithin, a typical phospholipin, contains one molecule each of phosphoric acid, oleic acid, palmitic acid and choline, and has a molecular weight of 794.

RESULTS

The growth of 5×10^6 tumor cells per mouse in 5 days in females is represented by Fig. 1. Tumor growth in mice on diet No. 2, which

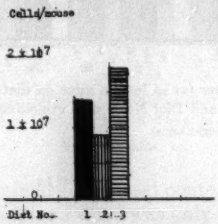

FIG. 1. Growth of Krebs ascites tumor cells in mice on diets 5 days. Diet No. 1 without, Diet No. 2 with and Diet No. 3 without ethionine.

contained ethionine was only 67 per cent as great as in mice on diet No. 1, which was the same except that it did not contain ethionine. Tumor growth in mice on diet No. 1, low protein, was only 77 per cent as great as in mice on diet No. 3, high protein, although neither contained ethionine.

The growth of 5×10^6 tumor cells per mouse in 6.5 days in females and the content (per cent wet weight) and composition of the fat of the livers of mice on diets No. 1 and No. 2 are shown in Fig. 2. Tumor growth was only 60 per cent as great in mice on diet No. 2 as in mice on diet No. 1. The fat content of the livers of mice on diet No. 2 was 2.2 times as much as that of the livers of mice on diet No. 1. It may be seen also that ethionine altered the composition of the liver fat; there was a marked decrease in the phospholipin and fatty acid fractions and a corresponding increase in the neutral fat fraction.

Although tumor growth in males was inhibited by ethionine to the

same extent as in females, the fat content of the liver, and the changes in the composition of the fat, after 11 days' growth, were small in comparison to those in females (Fig. 3).

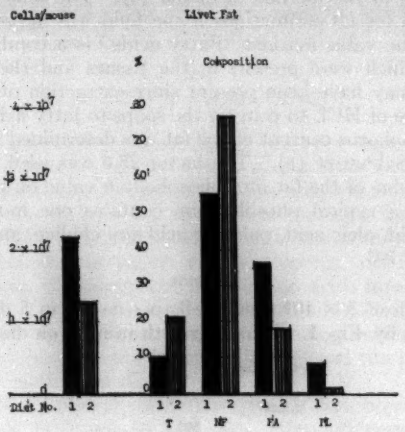

FIG. 2. Tumor growth and liver fat in female mice on diets 6.5 days. Diet No. 1 without and Diet No. 2 with ethionine.

T Total Fat (wet weight basis)
NF Neutral Fat
FA Fatty acids
PL Phospholipin

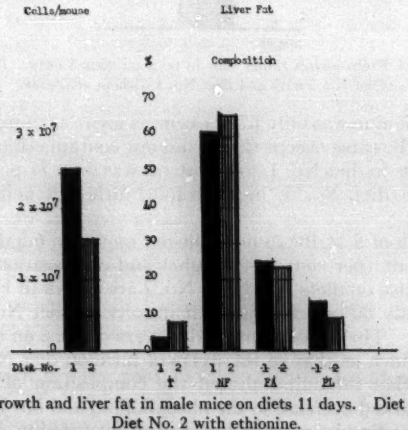

FIG. 3. Tumor growth and liver fat in male mice on diets 11 days. Diet No. 1 without and Diet No. 2 with ethionine.

T Total Fat (wet weight basis)
NF Neutral Fat
FA Fatty acids
PL Phospholipin

Ethionine in the diet of female mice induced similar effects on the quantity and composition of the fat of the tumor cells after 7 days' growth as it did on the fat of the liver, i.e., there was an increase in the fat content of the tumor cells, a decrease in the phospholipin and fatty acid fractions and a corresponding increase in the neutral fat fraction (Fig. 4).

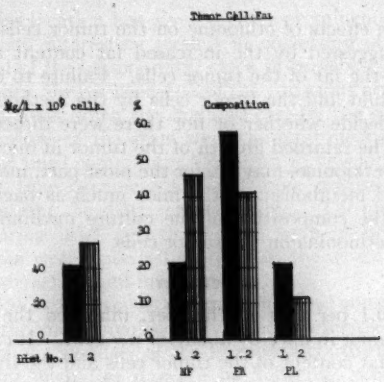

FIG. 4. Tumor growth and tumor cell fat in female mice on diets 7 days. Diet No. 1 without and Diet No. 2 with ethionine.

NF Neutral Fat FA Fatty acids PL Phospholipin

The glycogen (determined as glucose) content of the livers of tumor-bearing mice on diet No. 2 for 7 days was only 0.3 per cent (wet weight basis) whereas on diet No. 1, it was 13 per cent.

The fate of the ingested ethionine is not known. Paper chromatographic methods failed to show its presence in the tumor cells or the ascitic fluid either before or after hydrolysis of the cells and fluid by 1 *N* HCL for 2 hours at 105° C. Likewise, ethionine was not detected in an alcoholic extract of liver or in the extracted residue either before or after hydrolysis.

DISCUSSION

Ethionine caused profound derangement of the normal fat and carbohydrate metabolism of the mice as shown by these experiments and those of others (2, 6–13).

Since the ascites tumor cells obtain their nutrients from the peritoneal cavity, perhaps initially by attachment to the surfaces within the cavity and later as free cells from the ascitic fluid, their rate of multiplication should depend upon the nutritional state of the host animal. Immature mice gained weight more rapidly and tumor growth

was greater on diet No. 3, high protein, than on diet No. 1, low protein. (In earlier experiments, the gain in weight on diet No. 3 was 32 per cent in 17 days, on diet No. 1 it was 5 per cent.)

The small amount of glycogen in the livers of the mice on diet No. 2, which contained ethionine, suggest that the change in carbohydrate metabolism may have contributed to the decreased growth of the tumors.

Some of the effects of ethionine on the tumor cells, however, may be direct as suggested by the increased fat content and the altered composition of the fat of the tumor cells. Failure to detect ethionine in the ascitic fluid and the tumor cells by the method used makes it impossible to decide whether or not there were direct effects on the tumor cells. The retarded growth of the tumor in mice on diet No. 2, which contains ethionine, may be, for the most part, merely a reflection of the deranged metabolism of the mice much as bacterial growth is influenced by the composition of the culture medium, and not to a direct effect of ethionine on the tumor cells.

SUMMARY

Ethionine, 0.1 per cent in the diet, inhibited the growth of the Krebs ascites tumor in mice by about 30 per cent. It caused a marked increase in the fat content of the tumor cells and the liver, and altered the composition of the fat. The changes in the composition of the fat were (*a*) a decrease in the phospholipin and fatty acid fractions and (*b*) an increase in the neutral fat fraction. The glycogen content of the livers was reduced to a negligible amount. The effect of ethionine on the fat content and composition was more marked in females than in males, although tumor growth was inhibited equally.

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NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

THE STRASBOURG CLOCK

A change in its location has given greater prominence to one of the most elaborate and interesting models in possession of the Museum. This is the model of the astronomical clock in Strasbourg Cathedral.

Time telling has always been one of the conscious acts of mankind. There have been times when the shadows cast by the sun on a dial or the apparent motions of the stars were the only means of telling the time. It was not until community life began to develop that the need for knowing the time became acute and more precise methods were adopted for measuring the short periods of time. The most satisfactory means of measuring brief periods of time were at first mechanical. Once the elements were mastered there arose the desire to have something that was attractive and informative.

As early as 1382, the citizens of Strasbourg had constructed a clock that embodied the most involved mechanical principles then known. It became one of the wonders of the European continent. It suffered many vicissitudes, including damage by lightning, was repaired, and finally replaced by a new clock, thirty feet high.

The mechanical ingenuity displayed in the construction of this new clock can only be appreciated when it is known how many different types of time passage may be read. There are indicators which show the year, the month, and the date. Fixed and movable church feasts are shown, together with the solar cycle, the golden number, the dominical letter and epact used to determine the date of Easter.

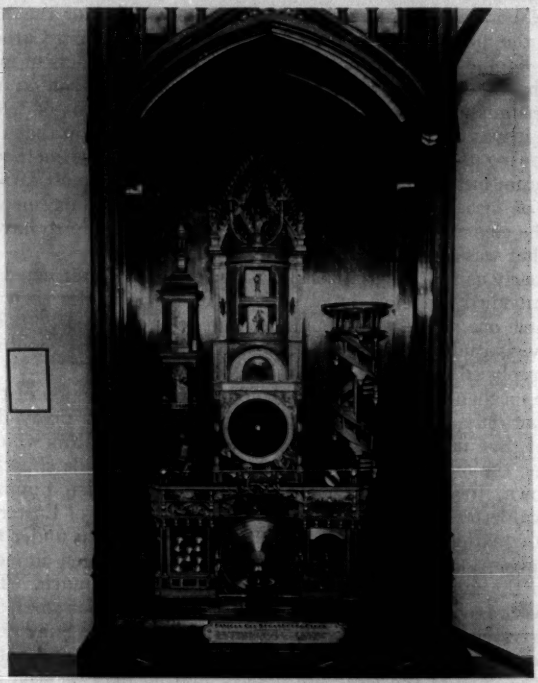
The equation of time for the current date is shown under the dial which gives mean solar time, so that it may be seen immediately whether the sun dial time is fast or slow and by how much. The day of the week is shown allegorically by a procession of seven small chariots that traverse a balcony. Apollo represents the sun for Sunday, Diana the moon for Monday, Mars, Mercury, Jupiter, Venus, and Saturn for whom the days of the week are named, and all may be seen in their chariots on their appropriate day of the week.

A celestial globe turns constantly to indicate which stars are above the horizon. The current phase of the moon is also shown at a glance.

All these are in addition to the function of telling the more prosaic hours of the day, and here, the engineer displays all his artistry to please those who must consult this particular clock. On the model in the Museum a conventional dial carries two sets of hands, one pointing to Philadelphia time and the other to Strasbourg time. On each side

of this clock an angel is seated and, on the original, one strikes the quarter hours with a scepter, and the other turns an hourglass filled with sand.

The quarter hours are also indicated by four figures representing the four stages of man, who march past the figure of death in a small gallery. At the striking of the hour a truly remarkable display is offered. In an upper gallery the twelve Apostles appear in turn, pause,



and make obeisance to the Saviour. At the same time a cock perched on the top of a tower ruffles his feathers and crows three times. To make certain that everyone knows the hour has arrived, the clock strikes the hour in conventional manner.

The model of this remarkable clock was made by the successors of the makers of the original clock. It was brought to this country by The John Wanamaker Store, through whose courtesy it is displayed in the Museum. For the benefit of visitors who may not wish to overlook such an interesting exhibit, it is displayed in the Planetarium Lobby.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES
FOR RESEARCH AND DEVELOPMENT
NICOL H. SMITH, DIRECTOR

ORDER-DISORDER AND COLD-WORK OF ALLOYS OF COPPER AND PALLADIUM

BY
F. E. JAUMOT, JR.

Scientists in the Solid State Physics Division have found that alloys of copper and palladium in the composition range from 6 to 30 atomic per cent palladium have unusual properties when subjected to cold-work distortion. Non-cold-worked alloys of this system exhibit the phenomena of order-disorder. That is, at temperatures above 475° C., they have a face-centered cubic structure with random probability of either a Cu or a Pd atom on a given lattice point; below this critical temperature, these alloys have either a face-centered cubic or a tetragonal structure with the Pd atoms on the corners of the cells. The most unusual feature of the ordering properties of these alloys is that they do not change volume on ordering; other common order-disorder alloys exhibit appreciable volume changes. This behavior supports the evidence, obtained from the cold-work study, that the interatomic distance is critical in these alloys.

When disordered copper-palladium alloys are cold-worked at room temperature, the electrical resistivity decreases; the magnetic susceptibility increases; the temperature coefficient of resistivity decreases; and the thermoelectric power becomes increasingly negative. The opposite situation is encountered when pure metals or normal alloys are cold-worked in all cases except the magnetic susceptibility; in most cases, the susceptibility is not appreciably affected by cold-working the material.

These very unusual results are explained tentatively as due to a fundamental change in the electronic structure of the alloys brought about by the cold-work distortion. More specifically, the only obvious explanation which will account for all the observed changes is that the density of electron states at the Fermi level is increased. This could be brought about either by supplying energy in such a way that the top of the Fermi distribution is moved up in energy from its position for disordered alloys, or the shape of the density of electron states curve as a function of energy is changed. On a physical picture, one could increase the density of states simply by moving the atoms apart. However, more experimental work is needed to determine if this is actually the cause for the anomalous behavior.

In addition to the above studies, the annealing kinetics of quenched and cold-worked alloys were studied. It was found that the growth of ordered domains probably occurs by a volume diffusion mechanism.

As a consequence of the anneal study and the supporting X-ray work required for all phases of the investigation, a rather drastic revision of the equilibrium diagram has been suggested.

This work was supported by the Office of Ordnance Research. Two papers describing the results have been accepted for publication in *Acta Metallurgica*.

ESSENTIALS OF BIOLOGICAL AND MEDICAL PHYSICS, by Ralph W. Stacy, David T. Williams, Ralph E. Worden, and Rex O. McMorris. 586 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $8.50.

Biophysics is a typical example of a fringe science. The fields of physics, physiology and biology have grown to such an extent that no longer is it possible for one human being to master all of them. Specialization has become a necessity. Years ago when only a few physical methods were applied in biological research, biophysics meant merely "the physics of the living organism." This means the application of physical methods to the exploration and explanation of live processes. Then came the discoveries of X-rays by Roentgen in 1895 and the γ-rays of radium by Pierre and Marie Curie in 1898. With these discoveries new problems gained predominence.

The biophysicist was now predominantly concerned with the study of the biological effect of physical agents. It is, therefore, not surprising that in Germany, for instance, biophysics was greatly advanced around 1918 by the work of F. Dessauer and W. Friedrich about the basic physical principles of the medical application of X-rays. It is probably no coincidence that one of the few periodical publications in this field in existence today, "Berichte der Physikalisch Medizinischen Gesellschaft" originated in Wuerzburg where Roentgen discovered his X-rays. Today with the fast growing technological age, the problems which fall into the realm of biophysics have vastly multiplied and with them the possibility that biophysics will eventually become a separate branch of science.

According to Loofbourow it encompasses the application of physical methods to the investigation of biological and biochemical problems, the study of the effects of external physical agents on living organism and biochemical substances and the physical phenomena occurring in living organism. Similarly, Rajewsky sees two distinct groups of problems in the general development of this science. First, there are all the problems of basic character which deal with the purely physical laws and phenomena in the synthesis and existence of living matter or their fundamental units. The objective is to bring the results in agreement with the general picture of Physics. The second group of problems is created by biology and medicine which apply the methods of physics. Here biophysics aids those sciences by giving the theoretical and experimental background in Physics in order to further efficiently their progress.

With biophysics being a growing field of activity claiming authority in its own right, many more steps have to be taken before the final goal of establishing an organized separate branch of science will be achieved. Meanwhile there are practically no biophysical journals and what is worse, there has been no text book for the new students which treats biophysics as a whole.

Essentials of Biological and Medical Physics is the first, badly needed, textbook which gives the student a comprehensive yet compact introduction into the field of biophysics. References at the end of each chapter are divided into general and specific references. The authors claim that these have been selected with the intention of leading to information of more detail than could be included in the text or leading to more complete bibliographies than one is able to find in their book.

The fast scientific and technological progress of the last 50 years emphasized many physical forces and the study of their influence upon the human being became a necessity. Consequently one finds paragraphs such as "Application of G-forces to living materials," "Insulation and endurance to temperature extremes," "The effect of high intensity sonic fields," "Gas biophysics of high altitude flight" and others.

The book is well organized and reflects clearly the principles involved in the application of physics to biology. To the teacher as well as to the student this will be a welcome guide through the many specialized fields such as radiation, electrical, acoustical, mechanical biophysics as well as an introduction to biophysics as such.

KARL SITTEL

LIGHT CALCULATIONS AND MEASUREMENTS, by H. A. E. Keitz. Translated by G. Ducloux. 413 pages, illustrations, 16 × 24 cm. Eindhoven (Holland), Philips' Gloeilampenfabrieken, 1955. Price, $7.50.

According to the author, "The purpose of the book is to deal with everything that the illuminating engineer or photometrist will need for his work, from first principles onwards." It is an elementary treatise, written for the practical photometrist who has little or no background in mathematics and physics.

The principal question that immediately arises on examining the book is "Why in 1955 should we have another photometric book in the spirit of 1760?" An English translation of Lambert's *Photometria* (1760) might be helpful, at least from an antiquarian standpoint. But a mere repetition of Lambert's point-source methods, already covered in dozens of books, seems futile. Of course, Mr. Keitz does not confine himself exclusively to what was known in 1760: he discusses the Bunsen grease-spot photometer (1843), the Hefner lamp (1884), the Ulbricht sphere (1900), the Rousseau diagram (1882), and the McAllister equilux sphere (1911). He even discusses photoelectric methods; but the flavor of the book is definitely reminiscent of the 1890's.

The truth is that lighting calculations, as well as lighting techniques, have been revolutionized in the last two decades. Calculations have progressed through three stages: point sources, surface sources, interflections. Point-source calculations were reasonably satisfactory in the days of the bare incandescent lamp, but they are quite inadequate today. The whole trend of modern lighting is toward large surface sources of low helios—the production of an optimum luminous environment for human living. Against this modern conception, the old emphasis on point sources, concentrated "fittings," and candlepower distributions seems thoroughly incongruous.

How are the three divisions treated in this book on "light calculations"? Point sources are emphasized throughout. A little discussion is given of surface sources, though the most important practical shape—the rectangle—is omitted. And essentially nothing is included on interflections.

Of course, one must recognize the desirability of avoiding complexity in an elementary book. But the tables or graphs for the general rectangular source are no more difficult to use than the point-source methods employed in the text. And if Mr. Keitz hesitated to include modern developments in interflection theory, he could at least have given the empirical data of Harrison and Anderson (1916). It would seem also that any treatise on photometrics should introduce the reader to such subjects as daylight calculations, colorimetrics, physiological optics, and astronomical photometry, all of which are omitted.

The rigor and accuracy can perhaps be inferred from a few quotations from the text:

". . . there were some very valid objections to the properties of the ether. . . . These objections were overcome by the *electromagnetic theory of light* formulated by Maxwell." (p. 2)

". . . the energy is evaluated in terms of the *sensation of light* produced in the eyes." (p. 23)

"Electrical light sources consume a certain amount of electrical power per second." (p. 33)

"The luminous flux emitted . . . or incident to a surface per unit area is known as the *luminous emittance*." (p. 102)

". . . luminous emittance, in the case of a surface that does not radiate light of itself, is identical with illumination." (p. 341)

"The image of such light sources [point sources] as formed on the retina is so small that it occupies only one of the light-sensitive elements of the retina." (p. 121).

PARRY MOON

HANDBOOK OF FOOD AND AGRICULTURE, edited by Fred C. Blanck. 1039 pages, 16 × 24 cm. New York, Reinhold Publishing Corp.; London, Chapman & Hall; 1955. Price, $12.50.

Handbook of Food and Agriculture represents the combined efforts of 29 authors, each specialists in their respective fields, to bring together in a single volume, under the editorial guidance of a capable experienced food scientist, the more pertinent information relating to food production, food preservation, and food usage. It consists of

26 chapters, arranged for the most part in a rather logical sequence, each of which pertains to a certain phase of the general subject matter.

The first four chapters are concerned primarily with soils, soil fertility, soil microbiology, and fertilizers and the second four with pest controls, growth regulants, enzymes, and oxidative rancidity and antioxidants. In Chapter 9 is presented a concise discussion of the essential nutrients. Chapters 10–13, inclusive, are concerned for the most part with food and feedstuff preservation and treat of storage of agricultural raw products, food preservation, effect of canning and dehydration, and food spoilage and deterioration. Chapters 14, 15, 16, 17, 18 and 20 are concerned with individual classes of foods and include: cereals and cereal products, dairy products, vegetable fats and oils, sea foods, animal products, and poultry products. In Chapter 19 is presented a rather comprehensive treatment of the chemistry of plant products. Chapters 21–24, inclusive, are concerned with the commercial aspects of the food industry and treat of such subject matter as food engineering, food packaging, food quality and quality control, disposal of food plant waste, etc. Chapters 25 and 26 cover very timely topics. The former is concerned with chemicals in foods and the latter is concerned with pertinent aspects of the Federal Food, Drug and Cosmetic Act, each being written by an eminent authority. Each of the 26 chapters contains an appropriate bibliography of reference literature.

In addition to the 26 chapters mentioned above, the volume contains a comprehensive appendix (109 pages) which includes useful information relating to: food laws and regulations, recommended dietary allowances, essential nutrients, food consumption and nutritive value data, policy regarding addition of specific nutrients to foods, specific food agencies, agricultural research institutes, FAO, WHO, research groups dealing with foods, special research institutes, commodity research groups, and to miscellaneous information pertaining to food research and food technology. The volume also contains a 48-page index which renders the information contained in the volume readily available. While the volume appears relatively free of errors, especially for a first printing, a rather conspicious typographical error does appear in the title of Chapter 5 (page 145).

The volume contains a wealth of information pertaining to the production, the preservation, and the use of foods. It should prove to be a useful source of information to the teacher and the student, to the researcher, and to the food technologist. It should prove particularly useful to the food producer, to the plant operator, and to others who have only limited library facilities at their disposal.

N. B. GUERRANT

CATALYSIS, Vol. 3, edited by P. H. Emmett. 504 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1955. Price, $12.00.

This is the third in a proposed series of seven volumes. It deals with catalytic reactions involving hydrogen. It describes fundamental approaches like the parahydrogen and orthodeuterium conversion and the hydrogen-deuterium exchange reaction (B. M. W. Trapnell), the catalytic hydrogenation of ethylene (D. D. Eley), the addition of hydrogen to carbon-carbon triple bond (G. C. Bond), together with more practical aspects of catalysis like the catalytic hydrogenation of olefinic hydrocarbons (B. B. Corson), the catalytic hydrogenation of nitro compounds (H. A. Smith, W. C. Bedoit, Jr.), the synthesis of ammonia from nitrogen and hydrogen (W. G. Frankenburg) the methanol synthesis (G. Natta), the hydrogenation of glyceride oils (R. O. Feuge), research on ammonia synthesis since 1940 (C. Bakhoven, C. van Heerden, R. Westrik, P. Zwietering), and catalytic dehydrogenation (K. K. Kearby). This is certainly an impressive list of subjects, whose reading gives a vivid impression of the amazing results obtained through research in catalysis. The presentation is generally clear and up to date. Some of the articles are more of an historical nature, but some others are really thought provoking. This volume is a very valuable addition to the previous two. It is a must for any scientist working in the field.

G. PARRAVANO

MICROWAVE SPECTROSCOPY, by C. H. Townes and A. L. Schawlow. 698 pages, diagrams 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $12.50.

Microwave spectroscopy as we know it today began in 1946 with the high resolution experiments with gases at low pressures. This was thirteen years after the pioneering experiments of Cleeton and Williams in 1933. These experimenters observed the absorption of centimeter radiation in Ammonia gas. It was not until World War II that microwave generators and detectors of high performance were developed. This development came about during the research program on Radar devices. The wavelengths of concern to the microwave spectroscopist range from a few centimeters down to a few millimeters. This is a frequency spread of from 10,000 to 100,000 megacycles. A large volume of published material now exists on the subject and this clear, basic and well written work by Townes and Schawlow is most welcome.

This book, which is one of the latest additions to the International Series in Pure and Applied Physics, is the most comprehensive treatment of microwave spectroscopy of gases published to date. The authors have written a book which while not intended primarily as a text provides excellent reference material for both researchers and graduate students.

The early chapters contain an adequate discussion of those parts of molecular and atomic spectra which are necessary for a basic understanding of microwave spectroscopy. Special attention is given to a discussion of atomic fine structure. The now famous Lamb-Retherford experiment is treated in some detail. The results of this experiment are in agreement with Dirac's relativistic quantum mechanical treatment of the hydrogen atom. The Dirac theory in contrast to the Bohr theory predicts a fine structure in the $n = 2$ levels of hydrogen. The observation of these predicted transitions is one of the outstanding contributions of microwave spectroscopy to atomic physics.

The writers deal quite extensively with systems containing, linear, symmetric, and antisymmetric molecules. Data taken from published works is described and the measuring techniques are outlined.

Special attention should be called to chapters 9, 10, and 11 which describe studies of magnetic hyperfine coupling constants and Stark splitting. The Stark effect provides a method of determining both the magnitude and direction of dipole moments of gases. Other methods usually yield only the magnitude. Another advantage which microwaves offer is that the dipole moment for a particular mode of vibration can be measured. Previously used techniques measure only an average moment over all of the states.

The chapters in the last part of the book deal with applications to chemistry and Astrophysics, microwave circuitry, and spectrographs. These chapters are extremely valuable to researchers already working in the field and those who may be planning to do work with this type of spectroscopy. Many block and schematic diagrams, descriptions of wave-guide components and abundant references are given in these sections. There is also included a discussion of millimeter wave spectroscopy which is beginning to approach the "never never" land of the electromagnetic spectrum which lies on the "long wavelength side" of the infrared region.

The authors are to be commended for their inclusion of the lengthly bibliography and the tables of pertinent molecular constants which are encountered in molecular studies. Drs. Townes and Schawlow have made an excellent presentation of a new and important branch of experimental physics. This book is highly recommended to the reader who is interested in molecular physics problems. JAMES B. DREW

ENGINEERING METALLURGY, by L. F. Mondolfo and Otto Zmeskal. 397 pages, diagrams and tables, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $7.50.

This book is intended to be a textbook of metallurgy for engineering students whose primary interest is in a field other than metallurgy, but who will deal with metals. This objective is very adequately fulfilled.

The book briefly, but comprehensively, surveys the field of metallurgy. Beginning with the extraction of metals, the authors lead the student into the basic theory of

metallurgy; that is, atomic structure, crystal structure, equilibrium diagrams, and the effect of crystal structure, electronic structure, and the distribution of phases on the properties of alloys. This is followed by a very nice correlation between directly applicable theory and its application in commercial practice. A pattern is established where a chapter on applied theory is followed by a chapter illustrating the commercial practice putting the theory to use. There is a chapter on casting theory, covering crystallization from the melt, shrinkage, segregation and inclusions. This is followed by a chapter on casting practice. There is a chapter on the theory of plastic deformation and of annealing; this is followed by a chapter on commercial hot and cold working practice including rolling, extruding, stamping, drawing, etc. A chapter on solid state phase transformations is followed by a chapter on commercial annealing and heat-treating practice. The book covers the joining of metals, powder metallurgy and corrosion. Appended to the text are two chapters—one on iron and similar metals, and the other on non-ferrous metals. These two chapters include a tabulated reference list of alloys, their properties and their uses.

Throughout, there is a slight emphasis on the design of metal products to avoid metallurgical problems in its manufacture. There is, for example, a section devoted to the design of pieces to be heat treated to prevent distortion and cracking on quenching. There is also a section on the design of castings.

The scope of this book is admirably comprehensive and the correlation between theory and practice is excellent. The explanations of theory are necessarily brief and often too brief for one who is introduced to the theory for the first time. This is especially true for the sections on atomic structure and on electron theory of metals. The student hardly has a chance to become acquainted with the terms involved. The concept of probability density with respect to electronic configuration is not introduced at all. The concept of Brillouin zones is not explained, but the authors are forced to use the zone theory to explain the differences between conductors, semi-conductors and insulators. The almost unavoidable lack of completeness may confuse the student; this shortcoming must be resolved by a teacher. That part of the theory which is more directly applied to metallurgy, e.g. equilibrium diagrams, plastic deformation, annealing, and solid state phase transformations is adequately explained.

An important part of this textbook is the problems appearing at the end of each chapter. They are well designed to make the student recall the factual information of the chapter and force him to use this information to reason beyond what is explicitly stated in the text.

The authors have prepared here a fine textbook that can be used not only for engineering students in a field other than metallurgy, but also as an introductory course for metallurgists. However, it is not a self-teaching textbook. It requires a teacher to help the student where the book's brevity may be confusing.

H. S. ROSENBAUM

SALAMANDERS & OTHER WORLDS, by Willy Ley. 293 pages, drawings, 15 × 22 cm. New York, Viking Press, 1955. Price, $3.95.

There are few authors who can weave a story with the matchless skill of Willy Ley. His popularity as an author will be enhanced by his latest adventures in Natural History which may be the last in a series of three begun in 1948.

In *Salamanders & Other Worlds* are found some of the fascinating answers to questions we ask today and these answers are guaranteed "conversation pieces" at the dinner table. As an example, he lays bare "Mitchurinism" and its chief disciple Lysenko. He explores the background of "The Abominable Snowman." The unearthing and identification of the *Archaeopteryx*—the missing link between reptile and bird is fascinatingly told. The "Tree of Death" and the man-eating tree legends are told and exploded. And finally some zoological excursions are recounted.

Salamanders & Other Worlds is light reading and ideal for a vacation fare which is precisely where this book was read.

I. M. LEVITT

CHEMISTRY OF THE SOIL, edited by Firman E. Bear. ACS Monograph No. 126. 373 pages, 16 × 24 cm. New York, Reinhold Publishing Corp., 1955. Price $8.75.

The book is a monograph sponsored by the American Chemical Society intended to inform chemists in unrelated fields with the field of soil chemistry and thereby stimulate further research in soil chemistry. It is not intended as a text for any formal college course, but it can serve excellently as a reference text for special assignments in advanced or graduate courses in soil chemistry.

It is a group effort written by 14 expert soil chemists. It is a most timely and welcomed publication since no authoritative text on soil chemistry existed previous to its publication. Most of the important fields of soil chemistry are covered in the ten chapters, each with good bibliographies. Included are chapters on soil development, chemical composition of soils, soil colloids and exchange phenomena, soil organic matter, plant nutrition and fixation of nutrients in the soil, oxidation-reduction reactions, soil reaction and salinity, and trace elements.

Since the chapters are written by different authors there is a marked lack of continuity in the book. Some overlapping of material particularly on soil colloids, is found in the book suggestive that the authors had not mutually reviewed the presentations of their colleagues. Some of the chapters are highly technical in nature and are not intended for beginners in the field. A chapter on methods in soil analysis is included in the appendix which should prove useful to soil chemists as well as chemists in unrelated fields.

A. C. RICHER

AN INTRODUCTION TO STOCHASTIC PROCESSES, by M. S. Bartlett. 312 pages, 15 × 22 cm. New York, Cambridge University Press, 1955. Price, $6.50.

This is a remarkable volume, typical of the kind of lucid texts which represent the thinking of British statisticians; it is compact, comprehensive, and provocative. Most certainly, it will be considered an authoritative source for many years to come.

By definition, stochastic processes involve a statistical or chance element in their structure. Therefore, any process regarded closely enough, is a stochastic process but the term is applied more specifically to processes which are very obviously random. Examples for such processes are found in all the sciences; by biologists to describe the growth of bacterial colonies; by modern physicists to observe cosmic ray showers; by telephone and air-traffic engineers to solve queues' problems; and by military scientists to study collisions of projectiles and rain drops. The chance element is the common core of all these problems: it leads to statistical description and model building. Much of the pertinent literature is scattered in separate papers and texts of a narrower scope. The collection of all this material into one volume will be welcomed by all statistically-minded researchers now actively engaged in related fields of study.

The book is addressed to a wide class of readers and it is appropriate that the author should first discuss the general probabilistic basis of stochastic processes. This discussion leads to the important concept of the characteristic functional which becomes a powerful tool in his hands. It is defined analogously to the well-known characteristic function for ANY random variable R_n extracted from a stochastic process $X(t)$. The second chapter on "Random Sequences" deals first with some of the now classical examples of stochastic processes: The Random Walk, Renewal Theory, Markov Chains, and Multiplicative Chains. The formal developments are held in vector notation and are illustrated by a number of sophisticated examples which include the Bush-Mosteller learning model and a model of genetic inbreeding.

The third chapter deals with processes in continuous time. Once more, the reader is invited to study Markov processes, but this time stress is placed upon the general structure. The decomposition of the process into a diffusion component and transition components, already given by Cramér, is reviewed. Then the forward and backward differential equations, first derived by Kolmogoroff in 1931, are derived for Markov chains specified in continuous time. Finally, the work of Feller on renewal processes is reviewed, both for discrete and continuous

time. There follows some interesting, original work on multiplicative chains which leads to various birth-and-death-rate problems, including immigration and emigration. The fourth chapter goes into a large number of miscellaneous applications and furnishes the needed exercises to the earlier chapters. Included are random walk problems, renewal processes, queues, population growth, bacterial mutations, population genetics, and epidemic theory.

The fifth chapter introduces and treats the notion of limiting stochastic operations on a stochastic process, such as differentiation, integration, series expansions, etc. These concepts lead to sums and difference equations for discrete times, and to differential equations and integrals for continuous time. Chapter 6 continues to develop the theory of stochastic equilibrium through further study of stationary processes. Among the concepts introduced is the spectral function $F(\omega)$, spectral moments, stationary point processes (where $d\ N(t) = 0$ or 1), generalized harmonic analysis, processes with continuous spectra, completely stationary processes, recurrence times, multivariate and multidimensional stationary processes, etc. The seventh chapter entitled "Prediction and Communication Theory" will be of interest to communication engineers seeking source material. It outlines linear prediction for stationary processes (in the Wiener sense) and Shannon's generalized communication theory.

Chapter 8, "The Statistical Analysis of Stochastic Processes," summarizes the statistical principles employed in the study of stochastic processes into two major categories: specification and inference. Discussed are the theory of maximum likelihood estimates for model parameters and statistical tests of one hypothesis against another. The examination of the inference problem for probability chains leads then to an exposition of the classical χ^2-theory of Fisher, and recent modifications thereof. Among the interesting examples analyzed in this chapter are an artificial Markov chain constructed with the aid of Tippet's random numbers and a 3×3 transition matrix (the series agrees quite well with expectation!). The final chapter outlines the correlation analysis of time-series. It is mainly concerned with real stationary time series and large-sampling theory since the theory is still largely in the developmental stage. Time series are considered for discrete and continuous times; among the excellent examples of this chapter is an artificial autoregressive series of 480 terms (Kendall 1946) with complete analysis. Other sections of this chapter include a discussion of periodogram analysis, and multivariate autoregressive series.

It is certainly impossible to condense into a few lines the wealth of material that the avid reader will find in this volume. The volume is even more impressive on second reading; its continued use is likely to give the reader a very mature viewpoint. At this time, the book occupies a central position on our bookshelf; it has served as reference on a number of occasions but its chief value lies in its comprehensiveness. The interested readers of this JOURNAL are invited to share this experience; books of this stature are neither written nor published very often! CARL HAMMER

VAPOR–PLATING, by C. F. Powell, I. E. Campbell and B. W. Gonser. 158 pages, illustrations, 15×24 cm. New York, John Wiley & Sons, Inc., 1955. Price, $5.50.

Since the beginning of the second World War, there have been considerable research and commercialization of processes pertaining to plating by metallic coats or related compounds. This activity has been stimulated by demands created by the appearance in massive numbers of products which before the war appeared only in dreams to the average layman. To name only a few, your reviewer can mention television, jet aircraft, and the mass production of die cast plastics.

Vapor plating, the deposit of film on a surface by decomposition of gases in the surrounding atmosphere, is only one of several techniques which accomplish the same end. These other techniques include electroplating, metal spraying, enamelling and evaporation. Each of these latter processes outshines all the others for some particular important application. For example, metal spraying is useful in "building

up" worn surfaces of expensive machine parts. Evaporation is indispensable in the application of non-reflecting films on lenses, and electroplating is used extensively in the application of corrosion-resistant metal films on more reactive base metals.

Vapor-Plating makes a strong point of the possibility that vapor-plating might play an important role in the plating (or coating) industry. This point is made by the revelation that a much greater variety of materials can be plated using this technique than by, say, metal spraying or electroplating, and in much thicker layers than evaporation. A considerable amount of description of film properties is provided which gives the reader a further basis of comparison with other techniques.

Perhaps one of the largest drawbacks in commercial adaptability was the paucity of description of the art in the literature. The book certainly takes a big step in eliminating that difficulty, since it is full of "helpful hints to the vapor-plater" including, for the many reactions revealed, film properties versus temperature of deposition, base temperature, rate of deposition, etc. The book also emphasizes, and none too strongly, the many drawbacks likely to befall the worker. These drawbacks should not be overlooked by the reader searching for a cure-all for the plating industry. But certainly the book, being the first single source of reference for information on the process, will help the process to find its proper place in the industry. ROBERT S. SMITH

CONDUCTION HEAT TRANSFER, by P. J. Schneider. 395 pages, diagrams, 16 × 24 cm. Cambridge, Mass., Addison-Wesley Series in Mechanical Engineering, Addison-Wesley Publishing Company, 1955. Price, $12.50.

This text on conduction heat transfer is designed for use in the first of a three semester sequence of graduate level courses on conduction, convection and radiation. Although the three kinds of heat transfer generally occur together, one mode usually predominates and is usually handled separately. The author makes no claim to originality and states that he has selected, abstracted and reframed in teachable form that material which he finds most suitable for exemplifying the principles and techniques of the field.

Analytical, graphical, numerical and experimental methods are ably covered. The organization of the text material is excellent, except that the reviewer feels that the review sections covering differential equations of Bessel, Legendre, Fourier Series and Laplace Transforms could be contained in the Appendix without loss of continuity.

The first nine chapters are devoted to steady-state conditions, with the first five chapters covering one-dimensional systems only. General systems of composite walls, tubes and spherical shells are considered, along with heat transfer in conduction-cooled turbine blades. In composite structures the author mentions the problem of thermal contact conductivity briefly. The effect of non-uniform thermal conductivity on heat transfer and thermal stresses is discussed. A section is included on the design of extended surfaces, for heat exchangers.

Except for the simplest geometric shapes and boundary conditions the analytical solution of the differential equations of heat conduction is extremely difficult. In many cases approximate solutions may be obtained by numerical, graphical methods or experimental methods. Chapters 6 and 7 include numerical and graphical methods for one and two dimensional problems.

Chapter 8 introduces heat sources. The author devotes a few pages to the subject of temperature fields in nuclear reactors and includes only a few examples and references on this expanding and tremendously important subject. The examples chosen on page 217 may cause some confusion. For example, the equation given in example 8-23 is not the general temperature distribution as stated, but rather the special case when the surface temperatures at the two exterior faces of the slab are equal. In addition, the equations are derived in terms of a specified distance into the slab. This distance only refers to the point where the temperature is a maximum and has no direct significance in determining cooling rates or stresses. With the tremendous wealth of declassified literature available on the temperature distribution and stresses in reactor components the reviewer feels that the author could

have performed a useful service by expanding this section considerably. The discussion of thermal stresses could be amplified.

Porous materials have potential application in reactors and other structures where other materials are not suitable for sustained operation at elevated temperatures. The author devotes Chapter 9 to this important subject.

The remaining chapters cover transient systems. Included in this section are transient heat flow in systems with internal heat sources and systems in which transient flow is caused by a moving source of heat within the solid. Considerable attention is given to graphical methods and experimental analogues. The section on experimental analogues offers a thorough discussion of available analogue methods and an extensive bibliography on the subject.

Since the reviewer is active in the nuclear power field the comments in regards to Chapter 8 are admittedly biased. Despite this criticism there are many admirable features in the book. The theory is presented in concise, orderly fashion along with a number of numerical examples. For a one semester course or as a reference in conduction heat transfer the text should prove very useful.

F. L. JACKSON

PUBLICATIONS RECEIVED

DIFFERENTIAL EQUATIONS, by Lester R. Ford. Second edition, 291 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $5.00.

MACHINE DESIGN, by Paul H. Black. Second edition, 469 pages, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $7.50.

HYDRODYNAMICS, by Garrett Birkhoff. Unabridged and unaltered republication of the first edition. 186 pages, illustrations, 14 × 20 cm. New York, Dover Publications, Inc., 1955. Price: $1.75 (paper); $3.50 (cloth).

NON-EUCLIDEAN GEOMETRY, by Roberto Bonola; and THE THEORY OF PARALLELS, by Nicholas Lobachevski, with a supplement containing THE SCIENCE OF ABSOLUTE SPACE, by John Bolyai. V.p., 14 × 20 cm. New York, Dover Publications, Inc., 1955. Price: $1.90 (paper); $3.95 (cloth).

THEORY OF GROUPS OF FINITE ORDER, by W. Burnside. Second edition, unabridged republication. 512 pages, 14 × 20 cm. New York, Dover Publications, Inc., 1955. Price: $2.00 (paper); $3.95 (cloth).

MONOGRAPHS ON TOPICS OF MODERN MATHEMATICS, edited by J. W. A. Young. Unabridged republication of the first edition. 416 pages, 14 × 20 cm. New York, Dover Publications, Inc., 1955. Price: $1.90 (paper); $3.95 (cloth).

REFERENCE TABLES FOR THERMOCOUPLES. NBS Circular 561. 84 pages, 20 × 26 cm. Washington, U. S. Dept. of Commerce, 1955. Price, $0.50 (foreign remittances must be in U. S. exchange and should include an additional one-third of the publication price to cover mailing costs).

BOOK NOTES

AN INTRODUCTION TO THE ELECTRONIC THEORY OF VALENCY, by J. C. Speakman. 180 pages, 13 × 19 cm. New York, St. Martin's Press, Inc.; London, Edward Arnold, Publisher; 1955. Price, $2.50.

This is the third edition of this book, which was first published twenty years ago. It is an elementary treatment of the basic concepts of the modern theory of the chemical bond. The first part, which has not been greatly altered since the earlier editions, describes the formal aspect of the electronic theory, the rules, and the different types of chemical bonds.

The second part deals with the applications of these idealized formulae to actual chemical substances. The treatment here is mainly descriptive and pictorial. The relationship between valency and the periodic system, coordination compounds, acid and bases, non-stoichiometric solids, the oxidation number, etc., are discussed. The treatment is clear and the book should be particularly useful for learning purposes.

MODERN PHYSICS, by John C. Slater. 322 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $5.50.

Since the advent of the atomic bomb a tremendous number of books have been published on various facets of the new physics, the atomic physics of the twentieth century. These have been well written by a representative cross section of the Physics community. However, most of these have stressed and encompassed the new science replete with mathematical formulae for the proper use by the student. The one feature which would appeal to the student and engineer, the history of the development, has been neglected.

Modern Physics by John C. Slater, Professor of Physics at the Massachusetts Institute of Technology, is a book designed to fill this gap. In his preface the author states: "Modern physics really is a branch of liberal culture, which should be of absorbing interest to the student of the history of thought and civilization." He deplores the marked differentiation of modern science and true culture. The author has tried to make this book a history of the development of ideas and he has succeeded in an admirable fashion. *Modern Physics* is a splendid contribution to the contemporary science panorama.

PROCESS ENGINEERING ECONOMICS, by Herbert E. Schweyer. 409 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $7.50.

The increasing emphasis on economics in engineering prompted the writing of this text. It presents basic economics and elementary accounting techniques as they are applied in the process industries, such as petroleum, chemicals, plastics, pharmaceuticals, metal refining, food and ceramics. Practical problems occupy an important part of the text. Apart from its value as a text, the book offers practicing engineers many ideas for saving money in design and operation. Four teaching plans are suggested in the Preface. The careful arrangement of text material makes it possible to use the book easily in courses of varying difficulty.

TUNGSTEN, by K. C. Li and Chung Yu Wang. Third edition, ACS Monograph No. 130, 506 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1955. Price, $14.00.

The revision of this ACS Monograph on tungsten will be welcomed by metallurgists, for the previous edition has been out of print for many years. In addition, new developments and new processes have necessitated drastic revisions and additions to the second edition. The purpose of the monograph remains the same—to cover the subject of tungsten thoroughly, including history, geology, ore dressing, industrial applications, substitutes and economics. Eight appendices cover related topics such as terms of purchase of ores from foreign countries, government regulations, The Tungsten Institute, etc.

ANTI-COMPOSITION TABLES FOR CARBON COMPOUNDS (CH, CHO, CHS, AND CHOS), by H. H. Hatt, T. Pearcey and A. Z. Szumer. 191 pages, 19 × 25 cm. New York, Cambridge University Press, 1955. Price, $4.00.

These tables have been prepared for the C.S.I.R.O. in Australia, as an aid to chemists in analyzing unknown organic chemical compounds of high molecular weight. The tables consist of compositions and the corresponding molecular formulae arranged in order of increasing percentage weight, first of one, and then, where necessary, of a second constituent element. The name "Anti-Composition" distinguishes these tables from the composition tables arranged in order of increasing molecular complexity. The present tables are used in obtaining formulae from composition data—for which regular composition tables are not suitable.

BUILDING PLANNING AND DESIGN STANDARDS, by Harold R. Sleeper. 331 pages, diagrams, 24 × 30 cm. New York, John Wiley & Sons, Inc., 1955. Price, $12.00.

Here, in one volume, architects, engineers, designers, consultants, draftsmen and students will find information on specific types of buildings, including small homes, hotels, bars, stadiums, banks, parking garages, hospitals, churches and 15 others. This is the first single volume to offer comprehensive data, from the preliminary planning stage through the drafting room. Diagrams and charts, construction details, specifications for equipment, and scale drawings bring the material to the reader in concise form. The detailed work involved in the preparation of this volume is staggering—but it should save untold hours of time for its users.

UNITED STATES ARMY IN WORLD WAR II. THE TECHNICAL SERVICES. THE ORDNANCE DEPARTMENT: PLANNING MUNITIONS FOR WAR, by Constance McLaughlin Green, Harry C. Thomson and Peter C. Roots. 542 pages, illustrations, 18 × 26 cm. Washington, Department of the Army, 1955. Price, $4.25.

This volume, one of the series "United States Army in World War II," is the first of three projected volumes on the Ordnance Department. Since its purpose is to discuss the steps which precede manufacture of munitions, it devotes 82 pages to a rather lengthy history of ordnance from Revolutionary times to 1939. The next section deals with the organization of ordnance for World War II, covering such topics as Military Personnel and Training, Civilian Personnel and Training, and Research and Development (1919–1940). The final section deals with research and development of weapons. This section will probably be of most interest to JOURNAL readers, for here is the story of research on all types of military equipment, from protective devices to bombs, from fire control to the bazooka. The book closes with a chapter on Unresolved Problems of Research and Development.

CHEMICAL ENGINEERING COST ESTIMATION, by Robert S. Aries and Robert D. Newton. 263 pages, charts, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $6.00.

As its title indicates, this book is a practical aid to chemical engineers, chemists, accountants, market researchers and executives, who are interested in making a profit on chemical plants. The principles of cost estimation are outlined, both with respect to new units and to ones already in operation. The quantitative approach is used so that direct application of the principles involved may be made. The material is up-to-date and thorough. Each of the ten chapters deals with a particular phase of cost estimation (capital investment, cost of equipment, manufacturing costs, general expense, plant location, etc.). The book should aid management in its job of evaluating project reports in the light of production feasibility.

THE COMPUTER DIRECTORY, 1955. 164 pages, 22 × 26 cm. New York, Berkeley Enterprises, Inc., 1955. Price, $6.00.

The June 1955 issue of *Computers and Automation* is The Computer Directory, 1955. It is divided into three parts: Part 1, Who's Who in the Computer Field; Part 2, Roster of Organizations in the Computer Field; Part 3, Products and Services for Sale. Part 1 contains about 7500 alpha-

betical entries; 2700 of these give the person's business connection, year of birth, college and computer interests; the remaining 4800 give only name, city and state. Part 2 lists alphabetically the companies engaged in some form of computer work (manufacture, assembly, parts, service). The listing gives the address, size of the company and lists its products. Part 3 lists companies alphabetically under separate classifications (adding machines, Card-to-Tape Converters, Data Retrieval, etc.) and lists the products or services they rent or sell.

BRAZING MANUAL, prepared by Committee on Brazing and Soldering, American Welding Society. 193 pages, illustrations, 16 × 24 cm. New York, Reinhold Publishing Corp., 1955. Price, $4.75.

The Committee on Brazing and Soldering of the American Welding Society, comprising the top experts of the country, has prepared a long-needed book on the subject of brazing. While brazing has been used since Biblical times, not until now has there been available a compilation, in a single source, of all the technical information on the eight brazing processes. Complete and valuable information is given on each of these processes: torch brazing, twin-carbon arc brazing, furnace brazing, induction brazing, resistance brazing, block brazing and flow brazing. Every conceivable metal of industrial importance, common and rare, is described in terms of techniques of brazing including equipment, precleaning, surface preparation, postbraze cleaning and inspection. An appendix in convenient chart form lists properties of brazeable metals and alloys such as aluminum, copper, brass, bronze, silver, nickel, gold, platinum, iridium, rhodium, palladium, tantalum, irons, steels, etc.

New Transistor Performs at Record-High Frequencies.—Bell Telephone Laboratories has announced that a new record has been achieved in operation of transistors at high frequencies. Experimental "junction tetrode" transistors, they report, have generated more than a billion oscillations per second.

Bell scientists have succeeded in stepping up the performance of these minute solid-state amplifiers well into the ultra-high frequency range used for certain types of radar and communications systems carrying television and large bundles of telephone conversations. This was accomplished by the addition of a fourth electrode to the basic junction transistor, plus other refinements.

Performance of the original junction transistor, announced by Bell Laboratories in 1948, was limited to lower frequency ranges. This earlier basic device, now in production by the Western Electric Co., manufacturing unit of the Bell System, is a three-layer "sandwich" of germanium sealed in a metal can a fraction of an inch in diameter. The outside layers are of n-type (negative) germanium; the central layer is of p-type (positive) germanium. Wire leads connect to each of the three layers and extend outside the can.

The more recent experimental device, known technically as the junction tetrode transistor, has been made to perform at very high frequencies by reducing the width of the germanium bar and the central p-layer, and by adding a fourth electrode. New techniques for producing the thin middle layer have recently made possible an almost ten-fold reduction in its width. In the billion cycle transistors, this layer is less than two ten-thousandths of an inch wide.

Telephone engineers are especially interested in broadband devices, such as the junction tetrode transistor, which enable hundreds of telephone conversations to be carried over a single pair of wires at one time. Until now this job has been done exclusively by vacuum tubes.

As compared with vacuum tubes, transistors have a number of important advantages. They are far less wasteful of power and do not get hot as vacuum tubes do. They are mechanically simple devices, made up of very few parts, and hence may eventually be very much cheaper than vacuum tubes. They can be made exceedingly small for use in compact electronic equipment. They are rugged and have a long life expectancy under properly controlled conditions.

While the new transistors are still in the experimental stage, Bell Laboratories' scientists have made considerable progress in learning to control processes in making them. Production by the Western Electric Co. is scheduled to begin this year, with initial output directed toward defense needs.

Easy Chlorination of Swimming Pools.—Olin Mathieson Chemical Corporation (Baltimore, Md.) now has available a new method for chlorinating swimming pool water that is easy, dependable, and requires no expensive investment in equipment. The method makes use of HTH tablet dissolving baskets, ribbed polyethylene containers which are designed to be fastened to the sides of the pool. This simple procedure, the company says, will provide a continuous, properly-distributed addition of chlorine to maintain a safe chlorine residual.

The system can be used for either fill-and-draw, flowing-through or recirculating pools. The company recommends using two baskets in pools of less than 20,000 gallons capacity. Larger pools use one basket for each 10,000 gallon capacity or fraction thereof. The baskets are hung at least 1 foot below the surface of the water. In recirculating pools they may be hung directly above or below the water inlet ports.

The company provides literature with charts showing recommended positioning of the baskets, average daily dosages of HTH tablets, and suggestions for handling the baskets.

HTH tablets, available both in 7½-lb. cans and in 100-lb. drums, are widely used for pool chlorination because they provide chlorine in a safe and easy to handle form. The tablets contain not less than 70 per cent available chlorine.

New Flame-Resistant Paint Finish.—National Gypsum Company (Buffalo, N. Y.) has announced that its Research Center has developed a flame-resistant paint finish for its wood fibre insulation board products. "The non-burning ingredients in this new finish practically eliminate the danger of flash fires and rapid fire spread," according to Dean D. Crandell, National's vice president in charge of research.

Describing the new finish as "a very important milestone in the development of fibre insulation board," Mr. Crandell said "it will permit the use of our interior fibre board products in commercial construction where a high degree of flame-resistance is of paramount importance."

Special Trailer for Launching Complete Bay of Bridge.—A special trailer has been developed by the Corps of Engineers' Research and Development Laboratories, Fort Belvoir, Va., to transport and launch a complete bay of the Army's new division floating bridge. Towed by a standard 5-ton bridge truck, it features a tilting bed with rollers which facilitate the launching of an assembled bay into the water. The rollers can be locked to prevent rotation while transporting a "ready" bay, and retracted to provide a flat bed for an unassembled bay of bridge. After the bay slides into the water, a power boat is used to retrieve it and maneuver it into position. Boats can also be hauled and launched by the trailer. Construction of complete bays on trailers in a rear assembly area eliminates the need for a crane at the site and speeds erection at rates never before approached with the bridge.

New Silicon Rectifiers with High Power Ratings.—Silicon rectifiers capable of handling up to several kilowatts of power have been announced by the Westinghouse Electric Corporation. The new diodes have a typical forward voltage drop of only 0.7 volts at a current of 8 amp. and at a cell temperature of 190° C. When mounted in a finned case 1 in. high and 1½ in. in diameter, this unit has a rating of 15 amp. at 200 volts peak inverse. This is with natural convection cooling in a 65° C. ambient.

At present, four voltage classifications are available: 50, 100, 150 and 200 volts. They have a forward current rating of 8 amp. with natural convection cooling at 25° C. Higher current ratings up to 40 amp. can be achieved with forced cooling.

Present applications of these diodes include such diverse fields as magnetic amplifiers, rotating rectifiers on the shafts of brushless generators, welders, plating lines and power packs.